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Sorghum—*Its Production, Utilization and Breeding*[1]

A corn-like cereal grass which among its 400 known varieties produces broomcorn, the principal material used in the manufacture of brooms, and important edible grains of Africa and Asia—durra, kafir, milo, shallu, kaoliang, feterita and hegari.

R. E. KARPER AND J. R. QUINBY[2]

Botany

Sorghum, *Sorghum vulgare* Pers., is a large grass of many varieties, cultivated throughout Africa and grown extensively also in India, China, Manchuria and the United States of America. It is sown and harvested as well in Asia Minor, Iran, Turkestan, Korea, Japan, Australia, southern Europe, Central America, South America and some islands of the East and West Indies, and is generally distributed from the tropics to latitudes as high as 45 degrees.

Sorghum was so named because of its height, from the Latin word "surgo" which means "arise". In the United States, where the species was introduced, there are now 400 varieties, but less than 50 of them are of commercial importance. In Africa and Asia, where the species is indigenous, numerous other varieties exist. These varieties, even including Sudan grass (var. *sudanensis* (Piper) Hitch.), cross-pollinate readily and produce fertile offspring. Most of the differentiating characteristics are known to be genetic, and there is justification to consider all varieties as belonging to the same species. However, the genetics of the differences that distinguish such groups of varieties as the broomcorns (var. *technicum* (Koern.) Fiori & Paoli), kafirs (var. *caffrorum* (Retz.) Hubb. & Rehder), kaoliangs (var. *nervosum* (Hack.) Forbes & Hemsley), milos (var. *subglabrescens* (Steud.) A. F. Hill), shallus (var. *Roxburghii* (Hack.) Haines), sumacs (var. *angolense* (Rendle), *etc.* are not well understood. At least one notable attempt to classify some 3,000 forms into 31 species has been made in recent years.

Johnson Grass and Sudan Grass. All varieties of *S. vulgare* are annuals, but some mention should be made of a closely related perennial sorghum, Johnson grass, *S. halapense* (L.) Pers., that is a useful grass or a serious pest, depending upon whether it is of economic value under particular circumstances. Johnson grass resembles Sudan grass but is less robust and produces extensively creeping rhizomes. Since Johnson grass is difficult to eradicate, it becomes a troublesome weed when it invades cultivated land. It has twice as many chromosomes as the other sorghums and crosses with them only rarely. Hybrids between the two species are partially sterile. Johnson grass, while undesirable on cultivated land in the southern States, is an important forage grass and is cultivated in warm climates in both hemispheres.

[1] Contribution No. 1043 from the Department of Agronomy, Texas Agricultural Experiment Station, College Station, Texas. Published with permission of the Director. Received for publication July 21, 1947.

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Sudan grass is a grassy counterpart of the coarser sorghums. The stems are smaller, the leaves narrower and tillering is more profuse than with other sorghums. The grassy nature of Sudan grass also shows in its lax heads and long narrow glumes.

Roots. The mature roots of sorghum are all adventitious, are fibrous and develop numerous laterals. The profuse branching and wide distribution of the root system is one reason why the sorghums are so remarkedly drought-resistant, but other factors also contribute to the drought resistance of the species. The plant grows slowly until the root system is well established, and at maturity the roots supply a leaf area approximately half that of corn. The plant can remain dormant during long periods of drought without death of the developing floral parts and can resume growth after conditions again become favorable.

Stems. The stems are erect and solid and grow in height from two to 15 feet. There is a lateral bud at each node. In some varieties, one, two or three of the lowermost buds develop into tillers, and this tillering is not considered undesirable. However, development of lateral buds at the higher nodes, which results in side-branches that mature later than the main head, is objectionable. The length of the internodes determines the height of the plant, and double-dwarf, dwarf and tall varieties with the same maturity have equal numbers of leaves, the difference in their stature being due entirely to internode length and not to number of nodes.

FIG. 1. "Sourless", a popular forage variety of sorghum, the vigorous growth of which results in yields of four tons of dry forage per acre.

Leaves. The leaves appear alternately on the stem, and leaf sheaths are

long and, in dwarf varieties, overlap. Varieties differ in leaf size, but all varieties have leaves somewhat smaller than those of corn, though similar in shape. Sorghum leaves inroll during periods of drought, and this characteristic contributes to the drought resistance of the species.

Flowers. The inflorescence of sorghum is called a "head" and is compact except in Sudan grass, broomcorn, shallu and a few sorgo varieties. The spikelets are of two kinds, sessil and pedicellate, the latter usually being staminate. Each sessil spikelet contains an ovary that develops into a seed after fertilization. The seeds are contained within glumes that cover them to a greater or less degree, and the glumes are usually black, red, brown or straw-colored. Sorghum flowers bloom during the early hours of the morning, and some reaction that takes place in darkness appears to be necessary for flowering. A sorghum head may contain as many as 6,000 florets whose anthers can produce up to 24,000,000 pollen grains. A panicle ordinarily blooms in five to seven days but consumes a longer time in cold weather. Sorghum is generally self-pollinated, but there is no barrier to cross-fertilization. When varieties are grown adjacent to one another, cross-fertilization of 5% is common. Sorghum pollen germinates immediately after being shed and retains its vitality less than an hour. The stigmas, however, are receptive for several days.

Grain. Sorghum grains are small in comparison to the grains of corn, and 12,000 to 30,000 are needed to weigh a pound. The seed may be white, red, yellow or brown, and the colors result from genetic complexes that involve the pericarp and testa. A large part of the caryopsis is endosperm, made up almost wholly of starch. Certain layers of some seeds contain considerable amounts of tannin, and sorgo varieties usually produce brown seeds of this sort.

Origin. The sorghums are considered to be of tropical origin. They are undoubtedly native to Africa, and it is possible that another center of origin may have occurred in Asia.

Photoperiodism. Sorghum is a short-day species, and this means that maturity is hastened when the light period of the day is short and the dark period is long. However, a difference in sensitivity to length of day occurs, and some varieties, such as broomcorn, are relatively insensitive. Hegari and milo are, on the other hand, quite sensitive to photoperiod. The differences in maturity that are common among sorghum varieties are a result of a difference in sensitivity to photoperiod or to a difference in critical photoperiod. Differences in response to photoperiod are genetic. Mutations have apparently taken place from time to time, and these have been used to extend cultivation of the species into higher latitudes. Insensitivity to photoperiod is apparently the result of thermal requirements, and so time of maturity in sorghum is influenced by both temperature and photoperiod.

Genetics. Sorghum has ten haploid chromosomes, and considerable genetic work has been done with the species in the United States, in India and in South Africa during the last 25 years. The inheritance of many genes is known, and four linkage groups, each involving more than three genes, have been reported.

Production

In the United States the acreage devoted to sorghum grown for all purposes increased to 20 million acres during the war period. This acreage is about double that grown prior to 1930. About 5% of it is devoted to the production of silage and about half the total acreage to the production of forage. In recent years almost half the acreage has been harvested for grain, and about two-thirds of the entire increase in acreage since 1930 has been devoted to sorghum

FIG. 2 (*Upper*). A field of harvested Early Hegari sorghum, a variety that is valuable for both grain and forage. This crop has been cut with a row binder and the bundles shocked. After drying in the shock the crop will be hauled and stacked, to be fed later to livestock, usually cattle. FIG. 3 (*Center*). A field of Plainsman sorghum that produced 65 bushels of grain per acre at Lubbock, Texas. The development of grain sorghum varieties of this dwarf stature has made this cereal of the Great Plains adapted to mass production. FIG. 4 (*Lower*). A field of the Plainsman variety, grown under irrigation and ready to be harvested with a combine harvester.

for grain production. Production of sorghum for sirup employs about 200,000 acres each year. Broomcorn occupies about 300,000 acres with concentrated areas of production in Illinois, Oklahoma, Colorado, New Mexico and Texas. Although sorghum, ranking in money value about with barley, is not one of the major crops in the United States, it is an important crop in the areas where production is concentrated. The newest area of extensive grain production is the Coastal Bend region of southern Texas. Production is concentrated in the Great Plains area from the Gulf to the Dakotas and in several interior valleys of Arizona and California. Sorghum is generally grown without irrigation except in Arizona, California and the South Plains area of Texas, but responds unusually well to irrigation. Where irrigation water is used, production is usually high, yields of 3,000 to 5,000 pounds of grain to the acre being common. Yields of unirrigated grain sorghum vary from a few hundred to 3,000 pounds.

Within recent years there has been a profound change in sorghum production in the United States that has been brought about because of the mechanization of the crop. This mechanization was possible because of certain inherited characteristics in the sorghum plant that were used by plant breeders to produce varieties of proper maturity and height so that they could be harvested with a combine harvester.

Since the species thrives in warm weather and is quite resistant to drought, sorghum is grown mostly in areas of the world where rainfall is insufficient for corn production.

Planting and Harvesting

Sorghums are grown in the United States from the Gulf of Mexico to South Dakota and from sea level on the Gulf to elevations close to or above 5,000 feet in parts of Texas, New Mexico and Colorado. Planting can be done on the Gulf Coast in late February, but is generally delayed until March or early April. The planting season progresses from south to north, and a favorable planting date in parts of Oklahoma or even further north is in July. Sorghums are grown, therefore, in environments where the days are 12 hours long and temperatures relatively low, in environments of 15-hour

FIG. 5. The use of hybrid vigor in sorghum awaits the solution of problems in the economical production of hybrid seed. Blackhull kafir and Day milo here appear on opposite sides of their first generation hybrid which has consistently produced 40% more grain than the varieties in general use.

days with high temperatures, and in all combinations of day length and temperature between the extreme limits. The environment on the Gulf Coast somewhat resembles that of Bombay Province in India where the "rabi" crop is grown during the winter months. The latitude in South Dakota is the same as that of Manchuria. India and Manchuria grow varieties of entirely different adaptation, but in the United States

some of the same varieties are being grown in southern Texas and in South Dakota. This is possible because varieties that mature early regardless of environment are being grown. In all probability varieties that will fit into specific environments will be better adapted than varieties that are early maturing, regardless of environment, and breeding work based on this assumption is under way.

Crops grown for forage, grain, sirup and broomcorn are almost invariably planted in cultivated rows. Harvesting of the grain, which at one time was done largely by hand, is now generally performed with a combine. The crop grown for forage is usually harvested with a row binder, the bundles shocked in the field until dry and then hauled and stacked. The silage crop may be harvested with a row binder, but the use of field ensilage cutters is becoming more common.

The production of sorgo or sweet sorghum for sirup-making extends from the Gulf States to Wisconsin and from New Mexico eastward. Sorgo sirup is most commonly grown to supply home needs, with the excess to be marketed, but there are a few commercial factories. The average production of sirup is approximately 60 gallons per acre. The making of sirup from sorghum, whether done with the usual rather simple equipment found on farms or in a commercial factory, consists essentially in crushing the juice from the stalks, removing impurities from the juice and concentrating the juice by evaporation. The leaves are stripped from the green plants and the heads removed before the juice is extracted.

About two million acres a year are devoted to Sudan grass, most of which is raised as pastures for cattle, hogs and poultry. A small part of this acreage is used for seed and hay production. Sudan grass, except for the acreage harvested for hay, is usually planted in cultivated rows.

Sorghum grains are small, and small amounts of seed, usually two to ten pounds per acre, are used in planting. Seed production is unique in some ways. One thousand to two thousand fold increases in grain are common, and therefore it is not difficult to maintain seed. However, numerous varieties exist, and, since there are different seed colors and plant heights and since cross-pollination occurs frequently, varieties must be well isolated or other precautions taken if varietal purity is to be maintained. Sorghums are susceptible to many diseases, but fortunately many of them can be controlled by a rather simple operation. A number of different smuts infect most varieties, but all of them can be controlled by proper seed treatment and in some cases by the use of resistant varieties. Since sorghum is grown almost entirely on an extensive scale and the acre value is not great, production is usually not attempted under conditions or in areas where foliage and other diseases limit it to any great extent. Sorghum becomes infected with most types of diseases that are common to other grasses, and usually control measures are not used. Where insects are extremely injurious, the crop is not grown. Insects that infest the grain are the common ones that give trouble with other cereals, and are controlled in the same manner as in corn and wheat.

Sorghums are usually grown for grain only in areas where corn is not reliable because of high temperatures and limited rainfall, or in corn-producing areas where planting must be done later in the season than is favorable for corn production.

Sorghum is susceptible to frost, and in the temperate zone is grown only as a warm season annual. In tropical countries, however, it is grown throughout the year but always as an annual. In

parts of India where frost does not occur, sorghum is raised throughout the year, but different varieties are used there in the different seasons.

Utilization

Sorghum has many uses throughout the world. Most of the crop produced in the United States will probably always be used as livestock feed, but in certain parts of Africa and India sorghum is the most important human food. In some parts of Asia sorghum stalks serve as a substitute for wood as a fuel and are used in making baskets, furniture, mats, shelter and fences. Brooms made from broomcorn, a sorghum in spite of its name, sweep floors throughout the world. In truck-growing regions of the United States, sorghum crops are plowed under to restore humus to the soil; and in the semi-arid regions of the Great Plains sorghum is planted in narrow strips and the stalks left standing to prevent soil erosion by the wind. And finally there is a definite tendency for increased use of sorghum grain in industry, as we shall note later.

Six-year Annual Averages of Acreage and Production of Sorghum in the United States 1940–1945

	Acreage 1,000 acres	Acre production	Total production
Silage	1,038	6.09 tons	6,317,600 tons
Forage	8,891	1.49 tons	13,221,209 tons
Grain	6,685	17.0 bushels	113,741,000 bushels
Broomcorn	277	320 pounds	44,549 tons
Sirup	192	60 gallons	11,574,000 gallons

Livestock Feed. Sorghum silage is considered equal in value to corn silage, and the annual production in the United States varies between four and nine million tons on a green weight basis. Practically all the silage produced is fed to cattle. Sorghum forage is harvested from an acreage about eight times as great as that harvested for silage, and the annual production of dry matter is usually in excess of ten million tons. This forage, which consists of all the aboveground parts of the plant, is fed mostly to cattle but also to horses and mules. Sorgo forage usually contains less than 20% of grain by weight, but grain sorghum forage is usually about one-third grain. Sorghum forage contains slightly less digestible nutrients than corn forage but is more palatable and can be fed with less loss. Dry sorghum forage contains slightly above 50% digestible nutrients which consist of 8% protein, 2.5% fat and 45% nitrogen-free extract. Properly cured sorghum forage with a little protein supplement will maintain livestock in good condition throughout the winter with little or no grain supplement. Shredded sorghum forage mixed with concentrates gives good results with dairy cattle and, during the period of heavy feeding, with beef cattle. Shredding is done in "feed mills" on the farm and the practice is justified, since grinding the entire plant causes even the coarse stalks to be consumed. Sorghum stover, which is sorghum forage with the heads removed, is frequently used as a rough feed where only a maintenance ration is desired. Cattle will always be the predominant livestock in sorghum-growing regions, since they can make better use of rough feed such as sorghum fodder than sheep or swine.

Sorghum grain is similar to corn but contains slightly more protein and slightly less fat. Sorghum grain can be substituted for corn in almost all places where corn is used as livestock feed, and feeding results indicate that pound for pound the two grains have almost identical value. Sorghum grain, unlike yel-

low corn, contains very little vitamin A. The chief use for sorghum grain is as feed for horses, mules, poultry, sheep, swine and cattle. The grain, which contains about 12% protein, 3% fat and 70% carbohydrate, is not a balanced ration, and protein supplements must be added for best results.

ture are commonplace. It is estimated that Sudan grass pastures occupy two million acres each year in the United States.

Sudan grass, as well as other sorghums, is sometimes grown for hay. The hay is nutritious but it somewhat difficult to cure.

FIG. 6 (*Left*). Recessive genes in sorghum may be used to great economic advantage. This strain, containing two recessive genes for height, can be combine-harvested because of its low stature. Three other recessive genes produce tan plant color, white seed color and waxy endosperm. FIG. 7 (*Right*). Stalks of the Early Hegari variety which is a popular dual service form, since it produces large yields of grain and nutritious stover.

Sudan grass is an important pasture crop in many areas of the United States and fills an important need, since it grows during the summer period when other sources of pasturage are scarce or lacking. Dairymen make extensive use of Sudan grass, and beef cattle gains of 2.5 pounds per day on Sudan grass pas-

Human Food. It seems unlikely that sorghum grain will become an important part of the diet in the United States, but in a considerable part of India, China and Africa it is the most important food. In Bombay Province 75% of the acreage is devoted to the production of sorghum, and the grain in some form is eaten at

each meal. The grain is ground each day in the home, otherwise the flour would become rancid on account of the embryo not being removed, and is made into flat, thin cake similar to the "tortilla" made from corn by the inhabitants of Mexico. In India sorghum is considered to be a more complete food than rice or wheat, but the reason for the belief is not very obvious. However, in South Africa the excellent health of the native Bantu children is often ascribed to the kafir mush that they eat. Kaoliang is an important human food in much of northern China. In the pioneer days of the American West, grain sorghum or "gyp corn", used as bread or porridge, frequently allowed a family to remain on the land after drought or other calamity had destroyed the wheat or corn crops. The use of sorghum for human food could be expanded greatly in the United States if the necessity arose, and formulas and recipes for using sorghum were published by several States and the Federal government during the first world war. Breakfast foods in attractive forms can probably be produced from sorghums. Pop sorghum is a desirable confection, and many other possible uses are easy to contemplate. A "sugary" gene similar to that which produces sweet corn occurs in sorghum.

A dessert, similar in taste and quality to tapioca, is now being manufactured from a "waxy" type of sorghum starch. Importation of cassava from the East Indies ceased during the war, and importation from that area in the future is uncertain because of the need of cassava there as food. It seems likely that the growing of "waxy" sorghum varieties in the United States will continue and that 20 to 50 thousand acres will be devoted to this purpose.

Numerous varieties of sorghum are grown for human food in India, and the "rabi" crop, grown in the season corresponding to late fall and winter in the temperate zone, is the most relished by humans and livestock as well. An observation of sorghum grain received from India indicates that the grain is usually freer from spotting and similar injury than grain produced in America. Since little sorghum grain is consumed by humans in the United States no great effort has been made to select for grain quality. Unlike American grain varieties, which are short in stature, Indian varieties are almost invariably tall. In India where the acreage cultivated by each family is small and where fodder is an important consideration, no esteem is attached to dwarf stature.

Sorghum sirup, of which more than 12 million gallons is consumed annually in the United States, is used for both table and culinary purposes. Sorghum sirup is an important part of the diet of many low-income families in the southern States and is most frequently eaten with biscuits made from wheat flour or with corn bread and butter. The quality of the sirup varies with variety, and soil type also has a definite influence on quality. Light sandy soils produce the "mildest" and most desirable sirup, but some hardy individuals like their sirup "strong".

Broomcorn Brooms. Broomcorn brush consists of the panicle that is harvested when the seeds are in the milk stage. The seeds are removed in a simple thresher, the brush is cured and then manufactured into brooms. Tall varieties produce the longest brush which makes the larger as well as the better quality brooms. Whisk brooms are made from a short statured variety that produces short brush. The annual production of brooms in the United States is about 200 million. Broomcorn has been cultivated in Europe for 300 years and in the United States since Benjamin Franklin began its culture with seeds plucked from an imported broom.

Industrial Uses. In addition to its

use as livestock feed, sorghum grain can be utilized in industry also in almost the same way as corn, and such industrial use of it is increasing. It would be easy to over-emphasize the importance of this industrial use in view of the fact that a large part of the crop will always be consumed by livestock and frequently on the farms where the crop will be produced. However, an increasing proportion of the sorghum grain that enters commerce will be used industrially, and some mention of the possible industrial uses is justified. Most of the sorghum grain that will be processed industrially will be for the production of starch, dextrose, dextrose sirup, edible oil and by-products. A factory with a capacity of six million bushels annually is at present under construction at Corpus Christi, Texas, and will be in operation in 1948. The seed coat of the grain of certain varieties contains a valuable wax similar to carnauba wax [from the leaves of a palm, *Copernicia cerifera* (Arr.) Mart.] imported from Brazil for use in furniture and shoe polishes. This wax constitutes about 1% of the grain and can be an important by-product of industrial processing when methods for its recovery are worked out. A waxy type of starch that has been mentioned previously is produced by some varieties and is being used to replace cassava starch that was formerly imported for use in making tapioca, adhesives and as sizing for textiles. Alcohol is produced from sorghum grain in quantities quite comparable to those obtained from wheat and corn, and considerable sorghum grain was used for this purpose during the war. Sorghum has desirable malting characteristics, and its use as brewers' grits is expanding. During the present world shortage of food, a certain amount of sorghum flour, usually not over 10%, is being added to wheat flour for shipment abroad to starving populations. As has been mentioned previously, almost any use to which corn can be put in industry can be duplicated with sorghum.

Varieties

Varieties of sorghum in the world apparently exist almost without number. Many of the varieties are kept in existence in primitive communities and their culture is quite limited. On the other hand, vast acreages are devoted to single varieties in India, Manchuria, South Africa, Argentina and the United States. The innumerable varieties that exist in tropical regions will probably never become familiar to inhabitants of the temperate zones, since their heading is delayed in high latitudes by the long days that occur there so that the grain fails to mature.

In any particular region, however, it is possible to become reasonably familiar with the groups of varieties that have agricultural value and even to become somewhat acquainted with many forms from other parts of the world. Except in areas of the world where large acreages are devoted to the production of grain for the commercial market, no value is placed on short stature and uniform maturity. Most of the varieties that have been received from India, China, Turkestan and Central Africa are tall. Grain that is used for human food is generally without a brown testa and lacks a brown pigment in the pericarp that is associated with high tannin content. Kaoliang varieties, however, usually have seeds with a brown testa and a brown pericarp. Kaoliang varieties are not, however, extremely high in tannin content. Varieties are classified roughly into "grain" or "sweet", and it is becoming a general practice in the United States to designate the grain varieties merely as "sorghums" and the sweet or saccharin varieties as "sorgos". Most sorgos have brown seeds that are unpalatable, due to tannin content, and

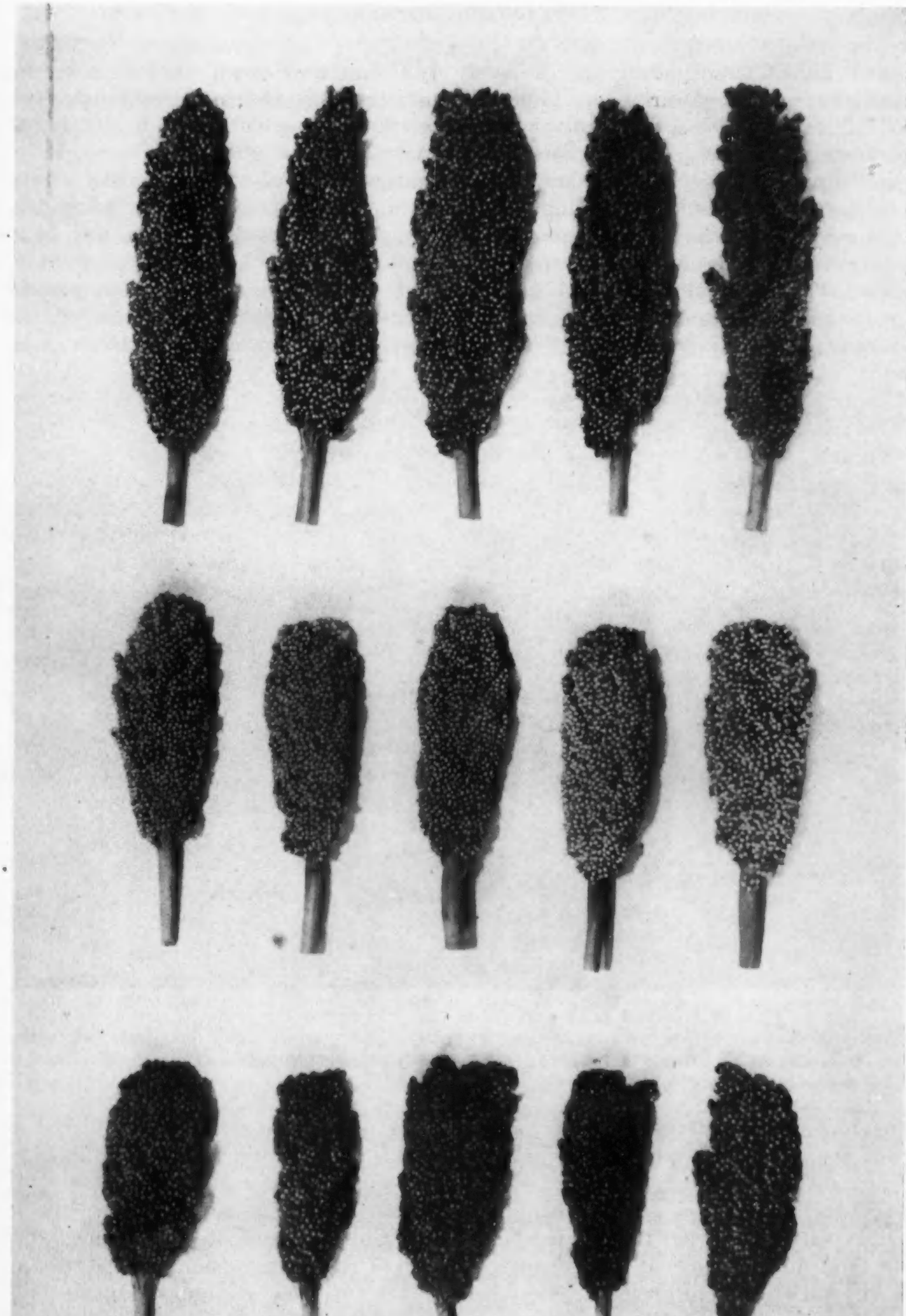

FIG. 8. Heads of Waxy Combine kafir (upper), Waxy Combine milo (center) and Cody (lower). These varieties produce seeds that contain a waxy type of starch used in the manufacture of tapioca, formerly made from imported cassava.

the grain of many do not thresh from the glumes.

The grain varieties frequently have a dry stalk that shows plainly, since the leaf midribs of such varieties are white. Juicy-stalked varieties, including all of the sorgos and many grain types, have leaves with opaque or translucent midribs. The common variety of Sudan grass has dry stems, but the improved variety Sweet Sudan has juicy stems. All broomcorn varieties have a dry stalk, but the stems of even the dry-stalked varieties contain some sugar.

There has been a drastic change in grain varieties during the last ten years in the United States but little change in sorgo varieties or in grain varieties that are harvested almost entirely in the form of forage. The change in grain varieties has come about to allow harvesting with a combine.

A botanical description of sorghum varieties is not easy to accomplish, even for the varieties cultivated in the United States, primarily because they are so numerous but also because many of the distinctions are agronomic. Identification of varieties from grain and head samples is possible, and a classification that makes use of length of panicle branches, presence or absence of the testa, presence or absence of awns, grain color and glume color was published as U.S.D.A. Technical Bulletin 506 in 1936. Mention will be made in the following paragraphs of the important varieties in the United States of the various types and of the distinguishing characteristics of the varieties. Several strains, usually of different maturities, exist of many of the varieties.

FIG. 9. Plats of Standard and Dwarf broomcorn. In harvesting, the tall variety is broken over with the plants from two rows forming a "table" about 4 feet high. The panicles are then cut from the stalks. Dwarf varieties are harvested by pulling the panicles from the stalk or cutting the peduncles just above the upper node of the stalk.

Sorgos. A list of the most important forage sorgos would include Sumac,

Sourless, Orange, Atlas, Honey and several Ambers. These varieties are midseason in maturity with the exception of Honey which is late and the Ambers which are early. Sumac is readily distinguished by its compact heads whose seed is dark reddish-brown. Sourless has less pericarp color than most other sorgos and the seeds are buff in color. There are a number of Orange strains that all differ slightly in appearance, and the Kansas Orange strain has red glumes. Atlas, which came from a kafir × Sourless cross, has white seeds and looks much like a tall kafir but has sweeter stems. Honey is late in maturity, has light reddish glumes, and the seeds do not thresh from the glumes. Black and Red Ambers are early in maturity and have seeds that do not thresh from the glumes. The glumes of Red Amber are much darker red in color than those of Honey.

Important sirup varieties are Hodo, Honey, Sapling, Gooseneck and Orange. Hodo is so late in maturity that it can be grown only in the extreme southern portions of the United States. The seed of Hodo somewhat resemble those of Sourless. Honey, which has been mentioned previously, is the most important sirup variety in much of the United States. Seed production of this variety is low, and sirup producers need to maintain their own seed supply or have knowledge of the source of their seed. There are several strains of Sapling. This variety makes sirup of good quality but has a tendency to "sugar". Gooseneck is a late maturing variety whose peduncles recurve under certain conditions. This variety was more important in the past than at present because seed sources have almost disappeared. A number of strains of Orange are used for sirup-making, and Rox Orange is the variety used by one large commercial sirup-making company. Any of the sorgo varieties, of which there are a hundred or more grown in the United States, can be used to make sirup, but sirup quality varies with each variety.

During the expansion of the West after the Civil War, it was thought that sorghum might be a source of sugar. Much work was done by workers in the Department of Agriculture at Sterling, Kansas, and some promising varieties for sugar extraction were developed. Difficulties, that have now been overcome, prevented the early work from resulting in a sugar-producing industry using sorghum. At present the chief interest in sorghum for sugar manufacture grows out of the fact that sorghum matures earlier than sugar cane and that by using both species the period of sugar manufacture can be extended. At Meridian, Mississippi, sorghum is being grown for use in a nearby sugar manufacturing plant that operates on sugar cane most of the season. The varieties best suited to sugar manufacture are Collier, Folger, and Straightneck which is a strain of Sapling. As has been mentioned previously, these "sugar" varieties are not considered to be the best "sirup" varieties because of the inclination of the sirup of these varieties to "crystallize".

A number of grain sorghum varieties are used extensively for forage. These varieties will apparently stay in existence for this purpose, but commercial grain production will make use of only early maturing double dwarf varieties. The forage-producing grain sorghums include Hegari, Early Hegari and Blackhull kafir. At high latitudes or in the northernmost sorghum-producing areas early maturing varieties of kafir derivation are in use. Hegari and Early Hegari are similar except for a difference in time of maturity. These two varieties are most palatable to livestock, even though the stems are not very sweet. Both varieties grow to be four to six feet tall, produce numerous large

leaves, and tiller considerably. The seeds are chalky-white and have a brown testa that does not show through the outer layer of the pericarp. Blackhull kafir grows to be four to six feet tall and tillers very little. The heads are long and erect, the seeds white, and a testa is lacking. Varieties with local adaptation are numerous, and there is reason to expect many varieties to remain in existence, even though they occupy only a relatively small acreage.

FIG. 10. Threshed and unthreshed broomcorn brush of three varieties. The European Dwarf is a common variety and the Fulltip and Scarborough Dwarf varieties are improved ones that originated in Oklahoma.

Varieties that are being produced for combine harvesting occupy the largest part of the grain-producing acreage. These varieties have been increasing in number and are extremely dwarf in stature, which results from being recessive for two genes that produce a shortening of the internodes. The list of varieties now in use includes Martin, Plainsman, Caprock, Westland, Midland, Combine kafir and the combine Sooner milos. With the exception of the Sooner milos

all the varieties named are selections from milo × kafir hybrids. The varieties are readily distinguishable agronomically. The first five varieties named have yellowish red seeds, and Martin is without awns. All these varieties have juicy stems. Combine kafir resembles Blackhull kafir but is shorter in stature. The combine Sooner milos, unlike the other varieties, are not the result of hybridization between varieties but are pure milo. One has seeds with white and the other with yellow pericarp. They are double dwarf in stature and are earlier in maturity than the other varieties. The distinguishing feature of all milos is the transverse wrinkle on the outer glume.

None of these combine varieties is more than ten years old and none is without some fault. It is likely that new varieties will soon replace those now in use.

Breeding

Much of the breeding work being done with sorghums is based on a knowledge of the inheritance of specific genes. The inheritance of genes that affect such characters as height of plant, juiciness and sweetness of stem, plant sap color, color of glumes, color of seed, type of endosperm starch and even duration of growth is known. The genetic constitution of the commonly grown sorghum varieties for many of the genes that are of economic importance is known, and it is possible to make an intelligent choice of parents with considerable assurance that a desirable strain will emerge from the cross as the result of recombination of the desired genes. It is undoubtedly true that many other characters of importance, such as resistance to diseases of several kinds, including those that produce lodging, and damage to seed in the field prior to harvest, are also genetic in nature. The sorghum species contains a wealth of variability, and much still remains to be done before most or all of the desirable characteristics have been brought together in a few strains.

An extensive sorghum-breeding program has been carried on in the United States during the past 30 years. The objectives generally have been greater yield through better adaptation, and better quality. Most of the sorghum improvement work now under way has some or all of the following objectives: more suitable maturity, more palatable seed, seed that will stand exposure with the least damage, dwarfness to make machine harvesting easier, insect resistance, disease resistance, improved forage quality, and endosperms with waxy type starch.

The mechanization of the sorghum crop that has taken place within the last ten years was possible because of the breeding work that has been done with the crop. When sorghum was introduced to this country less than 100 years ago the varieties were tall, but mutations that cause shortening of the internodes have occurred. Since grain sorghums have always been used by American farmers in large acreages, short stature was an advantage. The varieties that were commonly headed by hand in the years prior to mechanization were recessive for one gene which caused the varieties to be four or five feet tall, which is about the right height for hand heading. There is some correlation between height and the amount of lodging that occurs, and dwarfness is desirable in a variety to be combined. A second mutation that reduces internode length has occurred in sorghum, and plants that are recessive for two genes grow to a height of two to four feet. Such heights are most favorable for combine harvesting, and the efforts in recent years have been to obtain varieties of double-dwarf that are well adapted. The varieties in general use at present are all less than ten years old, and none

of them is considered to be without fault. Most of the efforts presently being made are for the purpose of improving varieties that are now being grown or to displace them with others that will be an improvement in one way or another.

One of the needs at present is to incorporate greater resistance to two fungus diseases that attack the stem and cause the plants to fall before or shortly after maturity but before the grain is dry enough to be stored without heating after combine harvesting. The presently used varieties are quite susceptible to fungus diseases that attack the grain during damp weather as the grain approaches maturity. Variations in resistance to this sort of attack exist, and one variety of Indian origin is quite resistant. Fortunately all the varieties now being used as parents as well as the commonly grown varieties are resistant to ***Pythium*** root rot, and the only precaution that needs to be taken is to see that susceptibility does not in some way get into the breeding stocks. Selection for resistance to this disease several years ago prevented the extinction of the important milo variety which at that time was the most important grain sorghum.

Increased resistance to insects, of which chinch bugs and grasshoppers are examples, is the objective of breeding work for particular areas where such insects frequently cause damage. In the northern part of the sorghum-producing area, the prussic acid content is sometimes high enough in sorghum forage to cause death of cattle. Selection for low prussic acid content has been effective.

There has been some breeding work done with Sudan grass, and at least three strains that contain certain genes obtained from sorgos have been distributed. Sweet Sudan grass has a distinctive glume color, is sweet and juicy, is somewhat resistant to foliage diseases, and is more palatable to cattle than the old variety. These characteristics were all transferred to Sudan grass from Leoti sorgo. Within the past three years this variety has come to occupy one-half of the acreage devoted to Sudan grass.

The manifestations of hybrid vigor in sorghum are pronounced. Much of the lateness and large size shown by some sorghum hybrids is due to the action of a few complimentary genes, but the vigorous growth and early maturity shown by corn hybrids also exist in sorghum. It is quite possible, if not probable, that the use of hybrid vigor in sorghum production will become feasible. Whenever an easy way to maintain a male-sterile stock in the homozygous condition is worked out or any easy way to bring about emasculation is devised, hybrid sorghum will quickly come into commercial use. Increases in yield as large as or larger than those obtained in corn are produced by certain sorghum hybrids. Hybrids are the easiest solution of several insect and disease problems. There is every expectation that sorghum hybrids will come into widespread use whenever hybrid seed can be produced economically.

As will be seen from the foregoing discussion, most of the urgency concerning breeding work with sorghum grows out of the mechanization of the crop, but there is also another cause. Sorghum grain is just entering a period of expanding use in industry. Two of the immediate problems that must be solved are the production of varieties with waxy endosperm that are suitable for combine harvesting and are satisfactory in production, and of varieties whose seeds do not produce undesirable water-soluble pigments when attacked by diseases or insects. Since many of the problems are new, much still remains to be done before the need for new sorghum varieties is met.

It may appear that almost all breeding objectives should be possible to at-

tain if enough variation exists in the species to embrace them. There is some reason to hope that this may be true, but there are some indications that plant breeders may have to be satisfied with less than perfection. Many of the genes being used in sorghum as a basis for improvement are desirable in the recessive condition. The height genes, juiciness, earliness and tan plant color that is associated with resistance to certain diseases are examples. Desirable hypothetical varieties might well contain two recessive genes for height, one for endosperm, two for plant sap colors, one for juiciness, two for seed color and at least one for duration of growth. It is now being generally assumed that recessive genes act as "inhibitors", and the possibility exists that an accumulation of too many recessives will inhibit the production of enough substances necessary to vigorous growth and development so that a multi-recessive variety will be too weak to produce satisfactorily. Probably the varieties that will finally become accepted will be compromises. They will contain the necessary recessive genes to make them useful for the purpose intended but will contain dominant genes that are not desirable except as they contribute to general vigor. At any rate, it now appears that sorghum varieties will increase in number for several years, but there is reason to expect a final reduction in number as varieties of over-all excellence come into existence.

Utilization Abstracts

Wood Distillation. The process of wood distillation was known to the ancient Egyptians who thereby recovered not only charcoal but also tar and pyroligneous acid which were used in embalming. Charcoal, however, long remained the principal product, and it was not until late in the 19th century that wood distillation became the chief source also of acetic acid, methanol, acetone, tar and wood oil. In the 1920's synthetic manufacture of acetic acid and of methanol were introduced, and since then the wood distillation industry has declined to a point where today in the United States less than 1,200 cords of wood are distilled daily. Charcoal is the only product that can not be made synthetically, and even some forms of it, such as activated charcoal, can be made from other raw materials, *e.g.*, pulping liquors and coal.

In general, distillation of wood yields about 25% charcoal, 2% crude methanol, 3% acetic and formic acids; the balance of tars and gases.

"Charcoal is used in blast furnaces and other metallurgical operations and in the manufacture of carbon disulfide, carbon tetrachloride and sodium cyanide. Methanol is used mainly as a denaturant of ethyl alcohol; antifreeze; solvent; methylating agent and ingredient in resins. Acid from distillation is especially suitable for textile operations, but also as a chemical raw material of wide importance. The tars and oils are used as rubber softeners, gasoline oxidation inhibitor oils, *etc.* The gases evolved contain 53 percent carbon dioxide, 27 percent carbon monoxide and 15 percent methane".

In one type of operation the process of distilling consists, in brief, of loading wood, cut into about one-foot-long lengths, into large retorts; sealing the latter; and then blowing through the wood heated gases that may raise the temperature to 1,000° F. without igniting the wood. The gases are those derived from the distillation itself and may be supplemented by other gases, such as natural, coal or oil gas. As a result volatile products are driven off from the wood, to be collected, and the remainder of the wood is thereby converted into charcoal. A cycle of operation, *i.e.*, charging the wood, carbonizing, cooling the charcoal and discharging, can be accomplished in 16 to 20 hours. (*R. S. Aries, Chemurgic Digest 6(11): 173. 1947*).

Ergot—*A Blessing and a Scourge*

Ergot, the black mass of a particular fungus on cereal grains, especially rye, was the cause of frightful epidemics in Europe more than a thousand years ago, and the ingested contaminated grain has occasioned disease in Russia as late as 1927 and in the United States a generation earlier. Medicinally administered, however, it provides a very important drug in the science of obstetrics.

H. W. YOUNGKEN, JR.[1]

Introduction

THE drug Ergot consists of the dried sclerotium of *Claviceps purpurea* (Fries) Tulasne developed on the infloresence of rye (*Secale cereale* L.) plants. To those mothers who have benefitted during child birth from the oxytocic effects produced by the alkaloidal constituents of Ergot there is perhaps the greatest admiration for the development and growth of this potent fungus sclerotium. But to men and women who in earlier times suffered from "Ergot disease", the result of eating cereal grains which were badly contaminated with ergot, the word has signified pain and death. Since the 6th century the cry "ergotism" has caused fear and need for precautions in gathering grain crops. Farmers whose fields have become infested with the fungus know of the damage it will cause to crops. Thus, this drug fungus during the advent of man's use of plants for food and medicine has played both a useful and a destructive role.

History

Pharmacopoeias and Dispensatories of many countries have long specified that the official drug Ergot must consist of the dried sclerotium of *Claviceps purpurea* (Fries) Tulasne developed on rye plants of *Secale cereale* L. The synonyms commonly assigned to the drug, such as "Ergot of Rye", "Spurred Rye", "Secale cornutum", "Horn seed" and "Mutterkorn", have resulted from the descriptive characters of the commercial rye ergot. Upon the introduction of ergot into official medicine which took place in the United States early in the 19th century there appeared in the "Medical Repository of New York" (1808) an "account of the *Pulvis parturiens* remedy for quickening childbirth". Further, this early description stated, "It is a vegetable and appears to be a spurious growth of rye. Rye which grows in a low wet ground yields it in greatest abundance". The great impetus to the use of rye as a source for the drug undoubtedly gained headway with the publication of a "Dissertation on the natural history and medicinal effects of *Secale cornutum*, or ergot" by Oliver Prescott and presented before the annual meeting of the Massachusetts Medical Society in 1813. This was later published in other languages. It was among the first United States publications which aroused interest universally in the obstetrical use of the fungus. Adam Lonicer's "Kreuterbuch" of 1582 and the reports of Paulizky in 1787 had indicated at an earlier period

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that the drug was used by the midwives of Europe, especially in Germany. With the aroused interest in the medicinal qualities of ergot of rye, focus was first placed upon the rye as the host plant for all medicinal preparations of the drug. In 1816, however, Jacob Bigelow, a medical botanist of Boston, made reference to the fact that the rye plant is not alone a source for ergot fungus infestation. In his publication "On the Clavus, or Ergot of Rye" Dr. Bigelow mentioned that wheat plants are infected similarly and that "considerable quantities of that ergot as well as domestic rye ergot have been offered for sale at the druggists' stores". This presumably would indicate that early during the 19th century the use of other than rye ergot was made by physicians and that shortly following the aroused interest in the drug much of the domestic supply was already established.

Although the knowledge concerning ergot and its medicinal virtues has been rapidly accumulated since the early 19th century, mention should be made of the significance of ergot and ergotized host plants to the ancients and to people of intermediate time, from 500 A.D. to 1800 A.D. Accounts vary considerably and are limited in regard to the early medicinal importance of ergotized grains. Schelenz and Achundow (1) reported that ergotized grains were used by the Chinese midwifery at an early date. Mention is made of its use similarly by Arabian medicine. There are evidences among the records of the Moorish physician, Avicenna, which indicate that the fungus was used medicinally during the 10th century.

The greatest historical significance of ergot and ergotized grains up to the 20th century has been the disease ergotism accompanying ergot-infected foods. This disease proved to be fatal to thousands during the endemic and pandemic plagues of Europe and Russia during the 10th, 11th and 12th centuries when the peasant class ingested ergotized grains. The disease was characterized by a gangrene development in the limbs of the victim due to the severe vasoconstriction and pressor actions of the ergot alkaloids. Such an action would eventually result in a numbness of the appendages, shrinkage and finally separation and dropping off. According to the description in the "Annales Xantenses" of 857 A.D., "a great plague of swollen blisters consumed the people by a loathsome rot, so that their limbs were loosened and fell off before death". The great ergot plagues of the middle ages, which were known as "Holy Fire", "St. Anthony's Fire", "St. Martial's Fire", the "ignius Beatae Virginis invisibilis or infernalis", were all associated with ergotized grains of the rye. Wahlin (2), who reported in 1765 on similar epidemics in the provinces of Jonkoping, Westergotland, Kronoberg, and Carlskrona, Sweden, has attributed the cause of the disease in these areas to ergotized barley and oats.

Kobert in 1889 made a study of the use of ergot among Greek and Roman times. He found substantial evidence for the fact that a true ergotism did exist among populations during the periods of Hippocrates, Dioscorides and Galen. This is interesting because of the general belief that rye plants were not commonly grown by the ancient Greeks and Romans. If this disease were true ergotism and not the result of the similar physiological action caused by eating corn darnel, black wheat or other smuts and rusts, it would indicate that ergot from cereals other than rye, perhaps fodder grasses, were of significance during Greek and Roman times.

Among the latest reports of ergotism from the ingestion of contaminated cereal grains are those concerning an outbreak of the disease in the States of New York, Ohio, Iowa and Kansas from

1820 to 1885. There was a similar outbreak as recently as 1926 and 1927 in the Ukraine region of Russia. These epidemics were from ergotized rye, wheat and oat grains. A small outbreak of ergotism occurred in Belgium during 1844 and was localized in Brussels. This was attributed to ergotized oats and rye.

Development of the Fungus

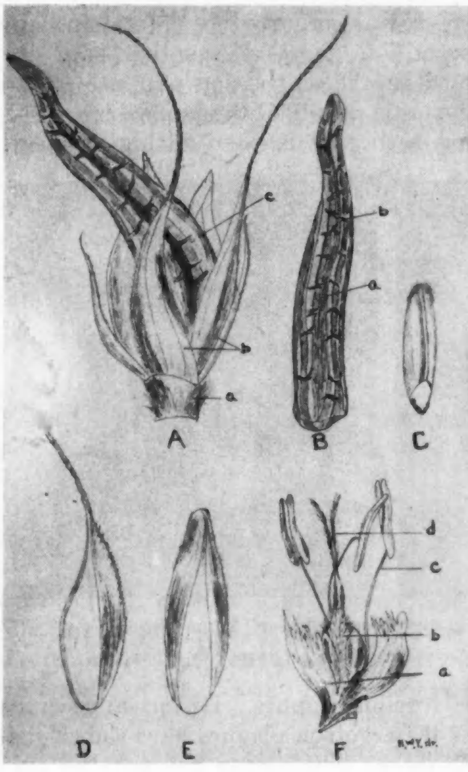
Botanists are well aware of the large number of grasses which are attacked by parasitic fungi. Many of these parasitized plants are susceptible to infections produced by species of the Ascomycete genus, *Claviceps.* The most common species of the genus is *Claviceps purpurea* (Fries) Tulasne. In 1822 the research of Fries, and later that of Tulasne (1852), made clear the nature of the life history of *Claviceps* development in infected grain ovaries. These workers divided the life cycle of the fungus into three phases in which the initial phase was termed the "sphacelium" stage or that form of fungus which attacks the delicate ovary of grasses; the second phase became the "sclerotium" stage or that stage which represents the resting period and which is characterized by a compact hard stroma or mass of mycelial tissue; and, third, the sexual fructification stage during which there arise also asexual fruiting bodies. The latter structures bear conceptacles, sporangia and spores.

The host plant, presumably always a member of the grass family, is attacked according to a consistent method of asexual spore dissemination. This takes place whenever parasitic *Claviceps* species in the form of ascospores or conidiospores (conidia) are present in sufficient numbers in fields of grain. Such is the rule during damp warm weather. By the agency of insects or wind these spores are scattered to young ovaries of a grain plant. The spores are lodged either singly or in clusters about the base of the grass ovary, and in the presence of moisture they soon begin to germinate. The first visible sign of germination is the presence of characteristic multiseptated hyphal filaments which appear to penetrate and spread over the basal portion of the ovary. These hyphal filaments branch profusely to form a dense fungous growth, the mycelium, which superficially covers the ovary. While the mycelium twists and branches over the ovarian tissues, fermenting substances, which are secreted by it, cause gradual decomposition of the entire ovary. The resulting mucous-like substance, called "honey dew", forms a spongy mass over the upper end of the ovary. In the meantime the modified ovarian structure increases in size. Close examination of the upper extremity of this structure reveals chains of asexual unicellular conidiospores in great numbers. These become abstricted and fall to the ground or are dispersed by means of insects. Such spores have been shown to retain viability for several years.

The release of conidiospores by the developing ergot ends what is called the "sphacelial phase" of the life-history. With penetration of the threads of mycelium deeper into the ovary of the grain a mass of fungal growth soon fills the space of the entire ovary. Microscopic examination of the ovary at this time reveals only a hardened compact mass of fungal tissue. Such a mass assumes a somewhat curved form and becomes the resting stage or sclerotium of the fungus. It is this purplish-black to brown hardened form which becomes the crude drug of commerce or the destructive form of ergot disease which is the menace to the grain grower.

The ergot sclerotium tends to dry somewhat within the spikelet of the grain and may remain there until the period of threshing, or may soon fall to

the ground. In any event, should it lodge on the ground, it will either develop fruiting stalks at once or remain dormant over winter and then sprout during the spring. The fruiting sprouts are characterized by the presence of many long-stalked globular heads (fruiting heads), each of which is called an "ascocarp" or "stroma". Within each ascocarp are flask-shaped cavities, the perithecia, each of which bears cup-shaped sacs or asci, each of which, in turn, encloses six to eight unicellular ascospores. After distintegration or rupture of the ascocarps, neighboring grains are quickly infected, and the fungus soon spreads over a wide area to ravage a grain field. If collected, however, these become the source for several medicinally important alkaloids.



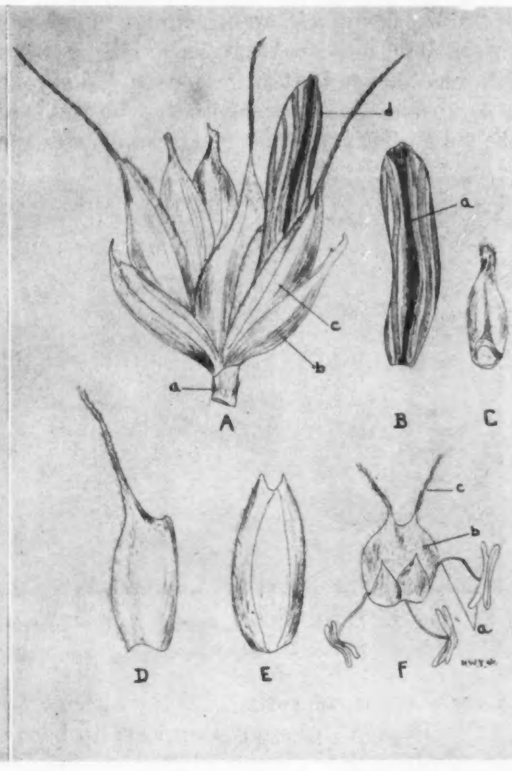


FIG. 1 (*Left*). Ergot developing in spikelet of domestic rye, *Secale cereale*. A, spikelet: a, rachilla; b, glumes; c, ergot sclerotium; B, ergot sclerotium: a, longitudinal furrow; b, transverse fissure; C, rye caryopsis: D, glume; E, lemma; F, flower: a, lodicules; b, ovary; c, stamen; d, style.

FIG. 2 (*Right*). Ergot developing in spikelet of domestic durum wheat, *Triticum durum*. A, spikelet: a, rachilla; b, c, glumes; d, ergot sclerotium; B, ergot scelortium: a, longitudinal furrow; C, wheat caryopsis; D, glume; E, lemma; F, flower: a, stamen; b, ovary; c, style and stigma.

Species of Claviceps

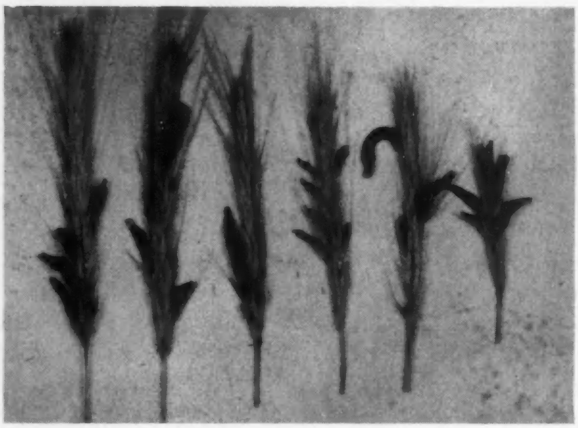
By means of artificially germinating the sclerotium stage of *Claviceps* spp. or by inoculation experiments, species of the genus have been studied for variations. It appears evident through the research of Barger (3) that, in general, each species is limited in development to a particular kind of host plant. For

example, *Claviceps nigricans* has been found restricted in development to plants of the Cyperaceae. Further, Reed and Vavilov (4) have shown that parasitic fungi inhabiting a number of host plants may be structurally alike, but that when transferred from one species of host to another no development will ensue. The assumption is often made that the spores of a particular race of *Claviceps* species can infect host plants susceptible only to that race. Stager (3) has shown that infection by *Claviceps* species may never proceed beyond the sphacelial stage in some grain ovaries to form ergot sclerotia. Of the species of *Claviceps*, *C. purpurea* appears to be the most fertile. Some 16 grasses, including wheat, rye, barley and species of *Festuca*, *Bromus* and *Poa*, as well as some of their hybrids, have been used with success as host plants during racial studies of sclerotia development in this species.

Among other economically important species of *Claviceps*, there are races of *C. microcephalia* which is an abundant infestor of the common reed, *Phragmites communis*, and of *Aira* spp., *Poa annua* and *Nardus stricta;* and races of *C. sesleriae* which were artificially produced by inoculation methods on *Melica uniflora* and *M. mutans* and later transferred to *Sesleria coerulea*. The latter grass appears to be immune to *C. purpurea* infestations.

Sources of Domestic Ergot

Since the acceptance into official medicine of ergot and its several important active alkaloidal constituents, such as ergotoxine, ergonovine, ergotamine and ergotinine, more interest has been created in the cultivation and use of the domestic supply of the crude drug. This has been especially so during shortages of foreign supplies. Historical accounts of the ergotism plagues have shown that European rye plants are not the only sources of a potentially potent Ergot, but that domestic grasses and sedges of additional types will act as hosts to potentially active ergots. Consequently, ergots growing on a number of domestic grasses and sedges have been investigated medicinally and physiologically. Many of these investigations have also been stimulated because of ethno-botanical findings. It has been shown as the result of such studies that sclerotia of the fungus *Claviceps*, no matter what the host plant may be, have medici-



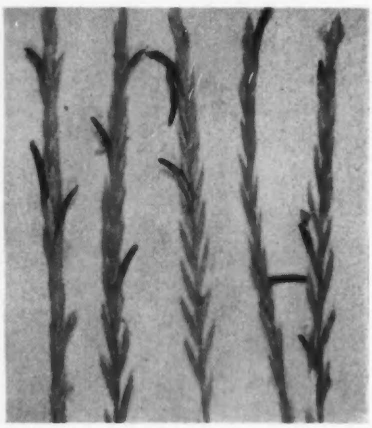


FIG. 3 (*Left*). Ergot developing on domestic rye, from fields of Minnesota.
FIG. 4 (*Right*). Ergot developing on domestic quack grass, *Agropyron repens*.

nal properties, such as vasoconstriction and muscle stimulation, which agree in character although not always in intensity of action. Among those domestic plants which harbor sclerotia most comparable to European rye ergot are *Agropyron repens, Glyceria nervata, Elymus virginicus, E. condensatus, Avena sativa, Zea mays, Palniae* spp., *Phleum pratense, Zizania aquatica, Ampelodesmos tenox, Triticum sativum, T. repens, T. durum, Lolium* spp. *Psamma* spp., *Dactylis* spp. and *Anthoxanthum* spp.

Barger (3) has listed the following number of known host plants for the ergot fungus; among the Gramineae, 66 genera including over 250 species; among the Cyperaceae, four genera, each with about ten species; among the Juncaceae, one species, *Juncus glaucus* Sibth.

Domestic Ergot compared with Foreign Ergot

In a study to compare commercial crude drug grades of domestic ergot with those of foreign importation into the United States, Youngken *et al.* (5) have shown that ergots from domestic rye, wheat and a wheat hybrid, *Triticum durum* Desf. crossed with *Elymus condensatus* Presl., compared very closely in structural and phytochemical characteristics with those from several European rye sources. Sclerotia of domestic and foreign rye ergots are generally larger in size than those of wheat ergot. Most domestic wheat ergots have conspicuously blunt extremities as compared with the tapering-to-pointed ends typical for rye ergots of both foreign and domestic sources. Rye ergots generally are larger in length and thickness than those of wheat, oat and rice. The pseudoparenchyma cells of domestic wheat ergots differ somewhat in being more compactly arranged than those of rye ergots. It is difficult to distinguish between these sources when powdered drug material is to be examined. Some domestic wheat ergots appear in drug markets with a striated marked outer rind. These are colored purplish-black with various tints of rose and have a smoother waxy surface than sclerotia of

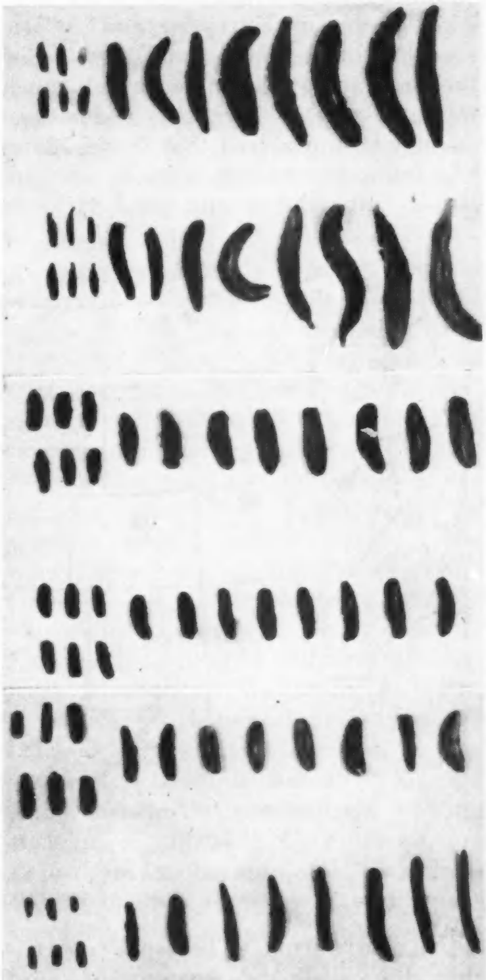


FIG. 5. Ergot from various sources, reading from top down: Spanish rye; Minnesota rye; Minnesota wheat; Minnesota durum wheat; "striated" ergot, domestic durum wheat; domestic hybrid, *Triticum durum* × *Elymus condensatus*.

other wheat, rye and oat ergots. These striated varieties appear to develop in large quantities in fields of the domestic wheat, *Triticum durum*.

There appears to be little or no striking differences in comparative results obtained from microchemical coloration tests, fixed oil determinations and moisture content for ergot of domestic rye or wheat sources when compared with good grades of European and Asiatic ergots. On the other hand, because of the poor conditions under which much foreign ergot is imported, it has frequently been observed that foreign drug is inferior to domestic ergot in morphological appearances and total yield of dried at a temperature not to exceed 40° C. Ergot which has been exposed to excessive moisture, more than 6% or 7%, will develop a brown-to-purple internal color instead of retaining its normay gray-to-white color. It will also possess a musty or rancid odor.

Physiological Reports on Domestic Ergots

There is a meagre amount of data available on the studies that have been conducted on the physiological activity of active constituents. The usual report is that the alkaloidal content of most sources of domestic ergots of rye are found to be greater than comparative imported sources. On the other hand, good quality ergot from domestic wheat supplies has been found to be lower in total alkaloid content than that of rye sources.

FIG. 6. Principal States producing rye, *Secale cereale* (lined circle); wheat, *Triticum aestivum* (open circle); and domestic giant wild rye, *Elymus condensatus* (black circle).

Storage and drying conditions for ergot of any source must be carefully observed. The drug should be stored in moisture-proof containers and should be ergots obtained only from domestic sources. The fact that the domestic supply has never reached the proportion of the imported supply has probably been responsible for manufacturers of ergot preparations to rely upon foreign shipments. This has been true as long as the latter have measured up to Pharmacopoeial specifications. Newcomb and Brown (6) and others have shown that domestic grown ergots compare favorably in physiological activity with selected samples of Spanish and Russian ergot.

In many cases they attach more value to domestic rye samples studied than to those of the foreign source. Munch (7) found that ergots obtained from quack grass, *Agropyron repens*, and from wheat, *Triticum aestivum*, both from fields in South Dakota, North Dakota and Minnesota, were from one to three times as potent in physiological activity as is required, according to minimum requirements for ergot of rye of United States Pharmacopoeia standards (U.S.P. X). Several samples of ergot obtained from rice, *Oriza sativa*, grown in Minnesota and assayed according to the U.S.P. XI cock's comb method, were found to be physiologically active and of good potency.

Denniston (8) has described the character of several ergot grains from wild rice, *Zizania aquatica* L., used by the Indians of northern Wisconsin predominantly in midwifery. Brown and Rauck (9) reported that the cause of several abortions among cattle in Mississippi and the Mississippi River Valley was due to the physiological activity produced by ergot of *Claviceps paspali* found infecting *Paspalum* species. There are reports of abortions among cattle grazing in ergot-infected rye, wheat, barley and other grasses of the West and Midwest.

The physiological activity of many ergots, in addition to the rye source, that are available within the United States, is attractive and warrants further investigation.

Economic Status of Ergot

Despite the indications of physiological activity produced by ergots of other than rye plants, the latter remain the chief ergot of clinical and manufacturing use. It is important that, due to the larger size of the rye ergot, this ergot is easier to separate from the grain, and such a factor influences its commercial availability.

Since the close of World War II the economic situation relative to the market in all botanical drugs has been improving and slowly returning to prewar levels. According to Industry Report (10) of the Department of Commerce and several of the trade news, many foreign suppliers of ergot of rye are returning to the markets. For example, during January and February of 1945 over 44,000 pounds of ergot of rye were imported. During the same months in 1946 about 42,000 pounds were obtained from abroad. In the shortage periods beginning in 1941 most American users of ergot were relying upon isolated spotty collections of the drug made by several crude botanical dealers within the United States. Wheat ergots as well as rye ergots were used by pharmaceutical manufacturers whenever large enough collections could be obtained. As much as three and four dollars per pound were paid for domestic drug. As a result of this, isolated areas of the wheat- and rye-producing States of the Midwest and South became important sources for the supply. Much domestic rye ergot has entered botanical markets from Minnesota, Wisconsin and the Dakotas. Other important sources are Illinois, Indiana and Nebraska. It has been estimated by the Bureau of Foreign and Domestic Commerce of the Department of Commerce (11) that during 1941 the United States produced about 100,000 pounds of ergot of rye, Spain supplied this country with 400,000 pounds, Russia 300,000 pounds, Portugal 150,000 pounds and Germany 100,000 pounds, and that from all other countries this country imported about 150,000 pounds.

It is evident that, although much ergot fungus develops annually in the wheat and rye fields of the country, relatively little of this domestic supply actually enters the drug markets during normal times. Due to the fact that only the rye source is acceptable for use as the official Pharmacopoeial drug, very little

wheat ergot is used commercially in pharmaceutical preparations. But even in cases of the rye ergot farmers prefer to burn the fungus rather than to compete with the foreign market or to run the risk of ergot-ravaged grain crops. Recent actions taken by the Federal Drug Administration in detaining many arrivals of ergot shipments from abroad because of poor quality drug has encouraged some grain growers to continue dealing with domestic outlets.

The collection of ergot is almost entirely a peasant industry abroad where it is usually picked by hand. Its domestic development or even that in foreign countries varies according to rainy seasons, heat and humidity. If not eradicated as a dangerous crop fungus growth, its collection varies from season to season. In the United States the fungus is separated by special machinery in terminal elevators which clean the ergot out of the rye and wheat. Some elevators retain the ergot screenings for sale, depending upon prices offered. Others destroy the screenings.

While dealers in crude ergot and manufacturers who use the drug replenished depleted stocks during the latter part of the war and into 1946, the price level remained between $1.65 and $3.00 per pound. In April, 1947, the price level reached to between $1.25 and $1.50 per pound. Even during normal times these price levels fluctuate, depending upon the rye crop prospects. For example, during 1931 and to 1934 the price range was between 32 cents and 47 cents per pound. From 1936 to 1940 the price ranged from a low of $1.25 to $3.85 per pound.

Conclusions

Despite the evidence of the physiological potency of ergot from other sources than the rye plant, the official standards do not permit those of wheat, oat, barley and rice to be marketed as United States Pharmacopoeial or National Formulary products. This restriction determines the foreign and domestic supply of the drug. Reports indicate that there is far more domestic wheat ergot developed in this country than domestic rye ergot. Considering the fact that prior to the past war more than 30 million bushels of rye were produced in a year in ten leading rye-producing States and that more than 490 million bushels of wheat were produced in the same year (1939) in ten leading wheat-producing States, potentially the wheat ergot and rye ergot yield should be great enough to become an important domestic source of drug.

It appears timely, therefore, that investigations be undertaken to develop the two foremost ergot supplies of the United States—rye and wheat ergot. Such an investigation might result in the use of wheat ergots in official medicines as well as that of the rye. This, it would seem, could be done under careful supervision so that there would be no fear of ravaged grain crops and the dreaded disease, ergotism.

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The Culture of Cork Oak in Spain

Where over-intensive use of the forests may be leading to the loss of a centuries-old plant-utilizing industry.

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Introduction

CORK is such a common, yet unobtrusive, material that we usually take it for granted with never a question as to its picturesque source or colorful history. While most of the common trees and shrubs, and even the herbs, produce some cork, only a half dozen species of plants produce enough to be of potential economic importance. The "corkwood" of commerce[3,4] from which cork products are made, is the outer bark of the cork oak (*Quercus Suber* L. and its varieties), a large evergreen oak that once girdled the Mediterranean but now is limited to the lands bordering the western half of that sea. A peculiarity that adds greatly to the value of cork oak is its ability to regenerate in a few years the corky outer bark after it has been peeled off or "stripped."

Cork has been, throughout historic time, one of the important agricultural products of Spain. It is closely linked with that most famous of Spanish industries, wine production, as well as being in its own right a major export product. Good husbandry has preserved the cork forests despite increasing economic pressures that might lead to their destruction, in the same way that many American forests were destroyed—by over-intensive use. The visitor with a knowledge of the history of forestry in the United States finds himself unconsciously watching for signs and for trends that will help him to estimate the status of the cork industry, to judge whether all is well or whether Spain, like

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[1] It was the writer's privilege, in the winter of 1943–44, to study cork production in Spain under the joint auspices of the U. S. Forest Service and the Crown Cork and Seal Co.,[2] of Baltimore. The comments and opinions expressed here are the result of actual observation and discussions with Spanish officials and business men interested in cork. The reader should bear in mind, however, that when judgments of so ramified a subject as the cork industry are based on only three months of observation, many mistakes are possible. Any misinterpretations of fact must be charged to the author—not to the hospitable Spaniards who did so much to make the assignment both pleasant and profitable.

On arriving in Lisbon, Mr. Melchor Marsa and Señor E. Mas were awaiting me, and three months later, on my return from Spain, Sr. Mas was again my generous host. Among the many Spanish officials and business men who unstintingly gave of their time and resources that I might have a better understanding of Spain and the cork industry were Señores E. Morales y Fraile, Salvador Robles Trueba, Luis Ceballos Fernandez, and El Marques de Villa-Alcazar, all of Madrid; Sr. Bonal of San Feliu de Guixols; Sr. Domingo Serra and Sr. Haya of Sevilla. Special acknowledgment is due Sr. Rogelio Mont Maruny of Sevilla who throughout my stay in Spain was my mentor, guide, business agent, host and loyal friend.

[2] See page 445 of this issue, and page 316 of Vol. 1 No. 3 of ECONOMIC BOTANY for abstracts concerning the cork oak-planting activities of the Crown Cork and Seal Co. [Ed.].

[3] Small amounts of cork are harvested from the "Pau Santo" (*Kielmeyera coriacea* Mart.) tree of Brazil for use in Rio de Janeiro and Buenos Aires. In Japan a small amount of cork is harvested from a native species of oak (*Quercus variabilis*) and used locally.

[4] The reader's attention is directed to the article on "The Cork Oak Tree in California" in Vol. 1 No. 1 of ECONOMIC BOTANY [Ed.].

the United States, is faced with shrinking forest resources.

Cork has several inherent characteristics that make it valuable to man. It is light in weight, buoyant, resilient, has a high coefficient of friction, is chemically inert, practically waterproof, tasteless, odorless, soft and warm to the touch and has pleasing texture and color. These qualities make it suitable for many things such as floats, stoppers, grips and handles, insulation and flooring. Substitutes for cork are plentiful in many fields of application. On the other hand, new uses are being found and old uses are being expanded so rapidly that the world production of some 300,000 long tons yearly is readily absorbed by an eager market of rising price.

History

When man first made use of cork is not known. Theophrastus, in 288 B.C., described cork as a product of the Pyrenees. Other early writers also mentioned cork and its qualities, indicating that long before the time of Christ, fishermen used it for net floats, vintners used it with pitch to seal wine jars, while Iberian peasants often roofed and floored their huts with cork slabs to insulate them from heat, cold and moisture. Today these same uses—floats for various purposes, stoppers and closures for fluids, and insulation—require the greater portion of the annual cork crop. One may even find occasional peasant huts in Spain that are roofed with cork slabs from the forest.

In the seventeenth century, with the development in Germany of the glass bottle, came the industrialization of cork. The craft of cork cutting emerged. Three quaint little seaside villages—Palamos, San Feliu de Guixols, Llagostera—in the north Spanish province of Gerona because the early centers of cork manufacture. Nimble fingered workers with keen-edged knives sat at their sidewalk benches and cut to order stoppers for wine bottles—as many as 2,500 per day by a skilled worker. German money and markets were largely responsible for the early development of the cork industry, but the shrewd energetic Catalans of north Spain became the factory managers, the technicians and the skilled labor of the industry. To this day a goodly portion of the directive and supervisory talent of the cork industry throughout the world is supplied by Spaniards, Catalans in particular.

Supply and Present Production in Spain

Of the 2,000,000 acres in Spain where cork grows naturally, only 840,000 acres are in commercial production today because of the thin stand of trees in the drier localities, the preponderance of other tree species than cork oak in many forests, or other factors that make commercial production unprofitable. The greater gross production of corkwood is in southern Spain, although northern cork is often said to be of better quality. The cultural practices of the two sections differ in detail due to differences in land ownership, land management and use, and the customs of the people. In north Spain the forest holdings of individuals are in smaller acreages, often consisting of woodlots adjacent to the small farms. In south Spain, on the other hand, are located tremendous estates that have been handed down within certain families for generations.

In the mountains and broken terrain, both in the north and in the south, dense forests may be seen. These are mostly of mixed oaks and other hardwood species. Cork oak may be scattered thinly among other kinds of trees, or in places it may comprise almost all of the stand. In the rolling hills and dry tablelands, particularly of south Spain, the forest consists of widely scattered hardwoods, often presenting the appearance of a

FIG. 1. (*Upper*). Old cork oaks along the road between Algeciras and Tarifa, Spain. The cement slabs along the road represent only safety precautionary measures.

FIG. 2. (*Lower*). Stacks of cork near Algeciras, Spain, awaiting shipment. (*Photos courtesy Crown Cork & Seal Co., Baltimore, Md.*)

sparsely wooded grassland. Here again the cork oak may comprise a large or a small part of the tree stand, depending on local conditions.

Always the cork oak is picturesque, with great gnarled branches and a wide spreading crown resembling the live oak of the southern United States. The trunks of some are smooth and cinnamon brown—young trees stripped of their corkwood for the first time within the year. Others show the scars and calluses of a hundred years of periodic stripping. In parts of the cork-producing country, particularly where the land is level or rolling, there is at times little reproduction of young trees. The visitor often has a disquieting premonition that the forest giants will one day be gone—with nothing to replace them. Yet the very presence of the forest, after three hundred years of intensive use, reassuringly demonstrates the value placed on conservation by the Spaniard.

Operations

Normal practice throughout the Mediterranean region is to strip the cork from trees more than eight inches in diameter in July, August and September. The Spaniard prefers for this operation a nicely balanced, short-handled, light weight broad-axe, centuries old in design. In some localities he chops a series of holes through the outer bark and uses them as a ladder to climb to the desired height. He then deftly hacks and peels the bark from the trunk in great slabs, often six feet long and half as wide, as he descends. A skilful workman strips about 1,200 pounds of cork per day. In North Africa and Portugal, ladders and saws are frequently used, but the fundamental process is essentially the same.

The time interval between strippings of the same tree is from 9 to 11 years, depending on the growth rate of the trees in the region in question. The forest owner seldom strips all trees the same year. He finds it more profitable to arrange the stripping of a part of his holdings each year. Corkwood is said to strip best after a rain, but as summer rains are very uncertain the harvest is planned without regard to the weather.

Local custom determines the method of disposing of the corkwood. After being stripped from the trees it may be piled near where it is stripped or it may be shipped by cart or wagon direct to the factory. More commonly, however, it is hauled to central concentration points in the forest where the cork of several owners may be assembled. Buyers examine the cork piles of the various owners before the auction, if one is to be held, so that they may bid intelligently on the various lots offered. One interesting variation of the auction is used extensively in north Africa and to a less extent in south Spain. The auctioneer first asks a price above what he expects to get. He then drops the price rapidly step by step until someone bids. The first bidder takes the lot being offered. The bidder must be shrewd and alert to secure for his company the quantity of cork desired at a favorable price. My respect for the cork buyers increased tremendously on closer acquaintance. In addition to the Spanish dialects, units of weight and money, the cork buyer for a large firm must be familiar with customs, money and languages of south France, Portugal and north Africa.

After the manufacturer has the cork in his possession it is graded very carefully into as many as 20 classes in some factories, depending on its fitness for various purposes. Cork grades are based on the size and thickness of the slabs; the presence of cracks, breaks and fissures in the "belly" or the "back" of the slab; the presence of pits, holes and injury or granular inclusions in the cork; the texture, density, color, presence of stains, uniformity, *etc.* of the material. The cork grader requires a

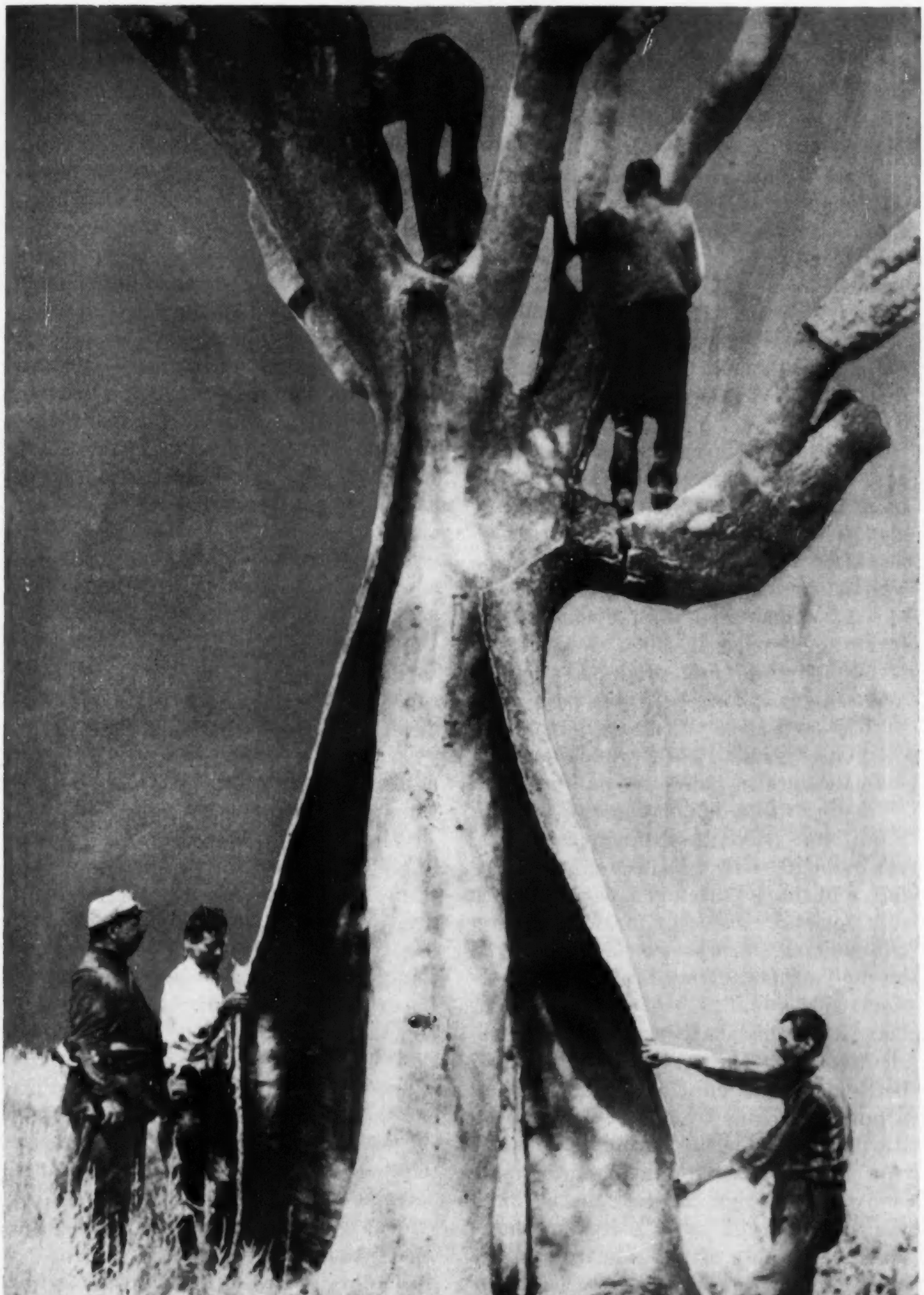

FIG. 3. Cork being stripped in one continuous piece 15 or more feet tall from the trunk of an old cork oak in Spain. (*Courtesy Crown Cork & Seal Co., Baltimore, Md.*)

keen eye, sensitive touch, thorough knowledge of grades and the uses to which they are put, and sound judgment; qualities that require years of experience to develop. Because of the small margin of profit on which cork is manufactured, improper grading could and sometimes does mean the difference between profit and loss to the factory.

Highest quality cork is made into stoppers for the sparkling wines such as champagne—in fact, the supreme test for cork quality seems to be whether it is suitable for champagne stoppers. Other grades of cork are used for stoppers for various sizes of bottles, for shoe insoles, crown cap liners, fish net floats, *etc.* The scrap left from cutting these products together with the low-grade cork is ground and used as hot pressed blocks for insulation, or for composition cork, the particles of which are cemented together. Cut cork products are still made chiefly in Europe, while the United States has become the leader in the production of ground cork products.

In the cork factories of Spain are seen all degrees of mechanization and working conditions. Shoe insoles are most often cut by hand, with the aid of a metal pattern and sharp knife, from sheets of cork that have been sliced by machine. Hand cut champagne corks are often preferred by the vintners. These are square in section with rounded corners, the belief being that this shape makes a more efficient seal than the round stopper. Small bottle corks are most often run through a punch machine by hand. It has been learned that a careful machine operator can cut more usable items from a single slab when feeding the machine by hand than can be cut by a fully automatic machine because of irregularities in size and shape of the slabs and the irregular distribution of imperfections in the cork. The trend, however, at the present time, is toward more automatic machines and more mechanization throughout the industry, because of the rising cost of labor in proportion to the value of the material wasted by machine cutting.

Working conditions in the Spanish cork factories are not comparable to those in the United States because of the entirely different social and economic system. During the winter the writer spent in Spain there was an acute shortage of electric power for light and heat and operation of machines due to drought and consequent low water storage. Cork factories in Sevilla operated only three days per week during part of the winter, with strict limitation of light and heat. The lack of heat was no great hardship, however, as there was no frost, and the midday temperatures were comparable to those of southern California or Arizona.

Economics

The visitor to Spain, if a botanist or a forester, is prone to speculate on future developments of the cork industry by what he sees today. Wherever he goes he sees evidence, bits of a pattern, that when fitted together form his picture of cork production as it is and as it seems likely to develop if present trends continue. There are several forces, rooted deep in custom, tradition and economic practice, that operate slowly but certainly to diminish the potential amount of cork that Spain can produce. To give an understanding of the complex situation these factors and those that counterbalance them must be examined. Some of the factors have been operative through two centuries or more, always tending to reduce not only the total acreage of cork forests but also the percent of cork oak in relation to other species. Among these factors are livestock husbandry, the use of cork oak for fuel, stripping injuries, cropping the land between trees, and subjugation of land for farming.

Grazing and foraging of forest land by

hogs, and to a less extent by other livestock, is an important and age-old business of Spain, in common with other western Mediterranean countries. It is the opinion of many forest landowners that over a period of years fees for allowing hogs to harvest the acorns will yield a greater and more dependable income than that from other forest sources. Light winter grazing by hogs and goats is believed to be beneficial to the forest, as many acorns are tramped into the ground where they sprout and grow. Heavy grazing by hogs or by goats has a bad effect at any time, particularly in a moist early spring when young trees may be chewed off, trampled or uprooted. Other classes of livestock, too, are capable of doing great damage to young trees and preventing reproduction of cork oak, but because they are fewer in number their damage is less.

The cork oak acorn, called the bitter acorn, is an excellent feed for livestock, and is sometimes eaten by the peasants during times of stress. On the other hand, the acorn of the holly oak, called the sweet acorn, is considered an even better feed. In addition, the holly oak bears a larger acorn crop per tree, and bears more regularly year by year than the cork oak. For these reasons the forest owner may sometimes favor reproduction of the holly oak rather than the cork oak because of its greater value as a producer of hog feed.

Cork oak, as well as other Spanish oaks, is excellent fuel and makes good charcoal, a vital and valuable product in Spain. Normally prunings, thinnings, and trees past the age of usefulness are converted into charcoal. At times the owner under economic pressure may convert many young, vigorous cork oaks into charcoal at the expense of future cork production.

Stripping also results in some loss. A loss of three to five percent of the trees is expected at the first stripping. After the first stripping the rate of loss drops sharply, but there are occasional losses of older trees, particularly when they are stripped severely, that is, when an unusually large area of bark is removed. Stripping also results in considerable accidental injury when the workman's axe may slip, or he may make his cut too deep. These injuries cause callus tissue knots to form, and in time, after many strippings, the cork oak trunk may become as warty as a cucumber. The quality of the corkwood produced by such trees is low, and they are often removed, the wood being converted into charcoal, the cork being stripped from even the smaller branches, and the inner bark being sold for leather tanning.

It is the practice in parts of Spain to plant crops between the scattered cork and holly oak trees during years when there is ample winter rainfall. Such cultivation, although not of outstanding importance, may, where it is practiced as often as once in five or six years, prevent the reproduction of young trees.

All of these practices and customs affect the long range outlook for cork production. The fluctuation of market prices sets the various trains of events in motion. During periods of high corkwood prices, trees are often severely stripped. Heavy tree losses and much trunk injury may result, particularly if the stripping season is followed by an unusually cold or dry winter.

During years of light demand and low corkwood prices, in order to produce necessary income, the forest owner may be forced to cut many trees for the production of charcoal, fuelwood and tanbark. A rise in price of any of these products may be reflected in heavier cutting of forest trees.

Likewise, when pork products are at a premium the forest may suffer. To take advantage of a favorable market, or of the relatively cheap feed, large numbers of hogs may be fattened in the

forest. Swineherders take half grown animals into the forests in late autumn. By spring the hogs are fat, having fed on acorns for five or six months: those from the deciduous oak in the autumn, from the cork oak in midwinter, and from the holly oak in late winter and spring. Much damage to young trees can result from this program unless great care and good judgment are exercised.

The Future of Cork in Spain

We have now examined at some length the factors that have slowly been depleting the cork-producing forests of Spain. In contrast to these let us examine some of the factors that have helped conserve the forest resources for three hundred years, or that give promise of helping in the future. In the first place it has long been the custom, so it is said, to periodically protect the forest from grazing or to allow only light grazing for a series of from five to ten consecutive years. If this is done once in fifty years the forest can be maintained. Then there has been in recent years an increasing interest in government acquisition and redistribution of large forest holdings and in the development and introduction of better forest practices. The chief of the Spanish Forest Service, Sr. Salvador Robles, is an able, well trained forester, who sees the problems clearly and who is advocating a sound and progressive program of education and control that makes the future encouraging. The effects of this program will be increased per acre cork yield, increased reproduction of young trees and less damage to trees during grazing and stripping operations.

Another greatly needed development that would, perhaps, protect the future supply of cork even more than regulation of the forest is the construction of large storage dams for hydroelectric power and irrigation. The potential waterpower that could be developed is great. Spanish engineers and agriculturists are looking in this direction. Power for factories and for city homes would greatly reduce the need for charcoal in this land without oil and with little coal. Water for irrigation would increase the supply of food and feed. The general effect would be to raise the economic status of much of Spain's population, and in so doing, to reduce the pressure for over-intensive use of the forest.

It will be interesting to watch the course of future development in Spain to see whether the colorful and historic cork industry continues to grow, or whether it is gradually crowded out by other industries that may prove to be of greater economic value, or whether the cork forests, as with some American forests, are destroyed by over-intensive use.

Utilization Abstracts

Sunflower Seed. In 1946, 25,000,000 acres of sunflowers were grown in the neighborhood of Altona, Manitoba, Canada, by the Mennonite farmers of that region. The crop was raised for production of sunflower oil which, since sunflower growing was started there three years ago, has found increasing use for household purposes, pharmaceuticals and shortening. The residual oil-meal cake, after the oil is pressed out, and the hulls are used by feed-mixing concerns. (*Agricultural and Industrial Progress in Canada,* as reported in *Chemurgic Digest 6(8): 151. 1947*).

Edible Nuts of the Pacific Northwest

Only four kinds of native nut—hazelnut, chinquapin and two acorns—and introduced American walnut, Persian walnut and European filbert constitute the sources of edible nuts in this region.

C. E. SCHUSTER[1]

Introduction

EARLY settlers in the Pacific Northwest found the Indians using the few edible nuts indigenous to that section. These were the hazelnut (*Corylus californica* Rose), nuts from the evergreen chinquapin (*Castanopsis chrysophylla* Dougl.) and acorns from two species of oak (*Quercus garryana* Dougl. and *Quercus kelloggii* Newb.). The pioneers themselves regularly gathered and used the hazel and chinquapin nuts, but the acorns were used only in cases of dire emergency.

Chinquapin

The chinquapin is widespread throughout the area west of the Cascade mountains. It is most common in the foothills or lower mountains where it at times becomes very abundant. A few years after forest fires in such sections, small chinquapin trees can be seen even ahead of other native trees. The nuts are small, resembling a beechnut, and relatively hard shelled for that type of nut. The difficulty of extracting them from spiny burs, competition with squirrels, and the occurrence of worms in the nuts often make gathering of the wild crop slow and tedious. But in spite of that, these nuts have in the past been seen on the market. No attempt has been made to improve by culture or select improved types for commercial use so far as is known.

The chinquapin tree reaches a height of 50 to 100 feet. On the average, though, most trees will be found smaller. Value for lumber purposes is only fair, as the logs are too small. The evergreen foliage and general appearance of the tree cause it to be used occasionally as an ornamental shrub or tree.

Hazelnut

Wild hazelnuts were apparently used more extensively by the Indians and pioneers than were chinquapin nuts. The nuts, while small and very hard shelled, still produced more edible food and were more easily gathered. Until the cultivated filbert was regularly sold in the markets, wild hazelnuts for sale could usually be found in small quantities each year in spite of importation of the European filberts.

The wild hazel bush is quite variable in size. On a dry rocky hillside it may never exceed eight feet in height. On fertile river bottom soil, crowded by competing growth of other kinds of trees and shrubs, it has been reported to reach a height of 30 feet. No use is made of the wood in any form.

Acorns

The acorns of the Oregon white oak (*Quercus garryana*) and the California black oak (*Q. kelloggii*) were apparently

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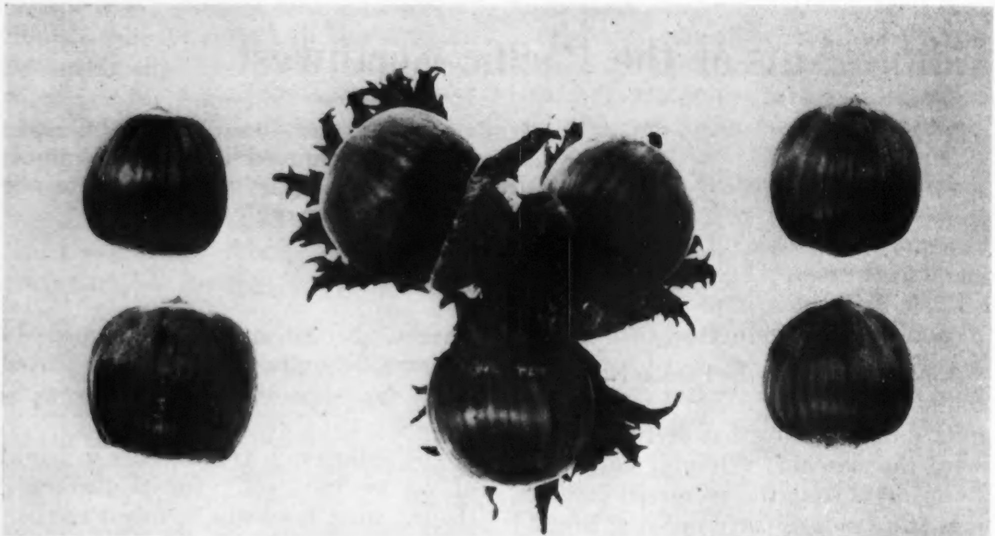

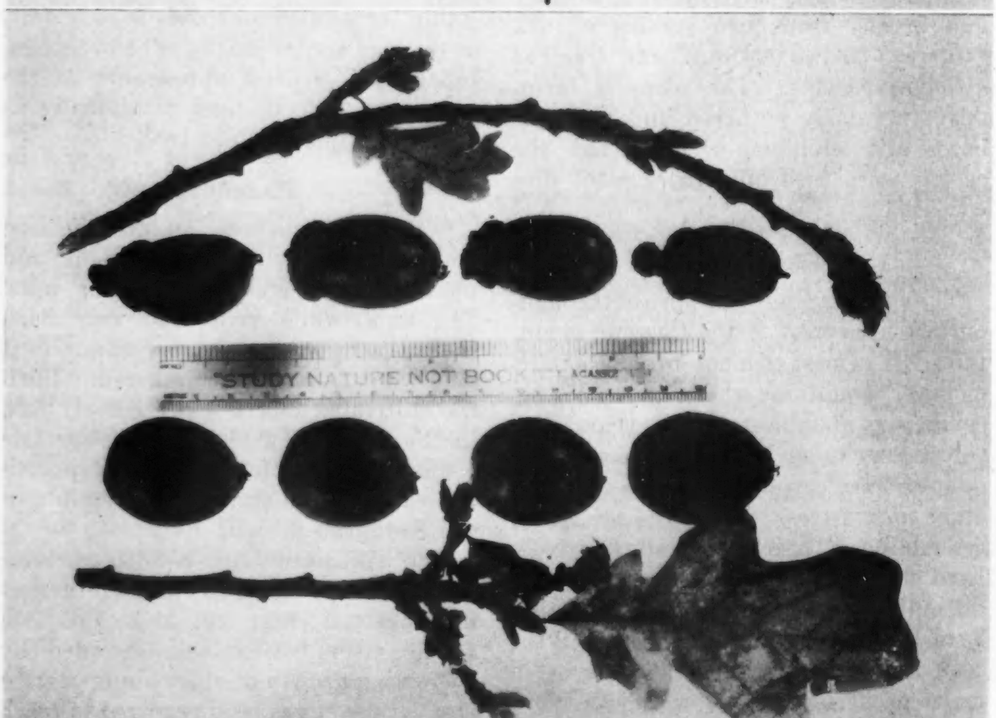

FIG. 1 (*Upper*). Barcelona filberts, the principal variety grown in the Pacific Northwest.
FIG. 2 (*Lower*). Acorns grown in southern Oregon.

in steady use by the Indians. Within recent years caches of such nuts have been plowed up where they were buried in wet ground to remove the tannin in the nuts. From limited information more use was made of the acorn in the southern part of the State of Oregon than in the northern parts. The north-

ern limit of the black oak is about in the Umpqua Valley of Oregon. The white oak is distributed from the northern to the southern boundaries of Oregon and northward through Washington, but the most productive areas are in the southern counties of Oregon. There the production of acorns is heavier and the size of the nuts larger than in the north, for instance, in the Willamette Valley. The lumber does not rate so high in value as does that of the white oak of other parts of the country, though it is used to a certain extent for furniture and similar purposes.

Walnuts

When the settlers came across the plains in the 1830's and 1840's they frequently brought along nuts of the black walnut (*Juglans nigra* L.), thus introducing this crop into the Pacific Northwest. When Henderson Luelling started his traveling nursery across the plains in 1847 he planted some black walnuts and hickory nuts in the wagon beds containing the nursery trees he was bringing to Oregon. These came up enroute and were undoubtedly distributed to the pioneers.

Soon after establishing the nursery at Milwaukie, Oregon, Luelling began growing Persian (English) walnut (*Juglans regia* L.) seedlings. The oldest surviving trees of this early date were planted in 1854 or 1856 near Scottsburg, Oregon, while one nut that was planted in 1855 near Dayton, Oregon, by Mrs. Joel Powell grew into an extremely large tree. Commercial plantings of Persian walnuts began in 1892 and were confined to seedlings, generally of French varieties. It was not until after the first World War that seedling trees were no longer sold and all plantings consisted of grafted trees, nearly all of the Franquette variety.

Varieties of Persian walnuts have been largely grafted onto seedling rootstocks of Hinds black walnut (*Juglans hindsii* Jeps.), commonly known as the Northern California black walnut. When white men came into northern California there were two small isolated stands of these trees which were soon cut down. Since then the nuts used by nurserymen have come from roadside trees. After the grafted trees reach an age of 15 to 30 years the union between the rootstock and the scion part of the tree often fail to form, and a layer of corky tissue develops. In a few years after this begins, the trees die. Many explanations have been suggested for this behavior. The most probable one seems to be that this trouble occurs when the rootstock is a hybrid; and since the seed parent trees are roadside or dooryard trees, usually not far away from Persian walnut trees, in many cases the seedlings are natural hybrids. Some have resorted to seedling rootstock grown from nuts of the Franquette to avoid this trouble, and others have rogued out the evident hybrids of the *Juglans hindsii* from the nursery. However, production of nursery trees for several years has been very small and of little commercial importance. Production of walnuts on the Pacific Coast has been rapidly increasing so that the marketing problem up to the time of World War II was very serious. With the advent of the war and the elimination of foreign imports the prices of walnuts rapidly rose, and walnut orchards were very profitable; but since the end of the war the market has been declining.

The tonnage of walnuts has been increasing steadily for years. The production in 1926 is given as 900 tons for Oregon. Since most of the limited tonnage of walnuts grown in the State of Washington has been processed at Oregon plants or marketed through sales agencies in Oregon, the tonnage of the two states has always been recorded as that of Oregon. The yield in 1946 is

given at 8,500 tons. In 1945, the last year for which farm values are available, a crop of 6,900 tons was worth $3,174,000 to the growers of this territory. Comparison of this with a yield of 900 tons valued at $450,000 shows the increasing importance of the walnut crop in the economy of this area.

In the early years of marketing all the walnuts were sold in the shell. As the tonnage increased and marketing became more difficult, a certain percentage of the nuts were cracked and the kernels sold direct to processors and manufacturers. The trend is more in that direction as time goes on, though it was interrupted by the war.

Such byproducts as walnut oil are negligible or non-existent. One product—ground walnut shell or walnut flour—is on the market commercially. Any other byproduct, if being sold at all, is marketed only in very limited amounts. However, byproduct possibilities are being explored intensively at this time.

As the walnut orchards became older and crowded, it was necessary to pull out part of the trees. Attempts to dispose of the trunks to make into lumber have been unsuccessful for the most part in Oregon. Even in the case of the black walnut, only the very old trees that are suitable for veneer material have found a ready market.

Walnut trees are planted in orchards at distances of 40 to 60 feet apart. The orchards are either the sole project of the owner or are a part of the farm. They are clean-cultivated during summer, and a cover crop is planted in the fall to plow down in the spring. The disease control work needed consists of spraying or dusting before and after full bloom, two to four times in all, to control walnut blight. Harvest is usually in October. The nuts are picked

FIG. 3. Harvesting scene in a walnut orchard in the Willamette Valley, Oregon.

from the ground on a piecework basis. Shaking the trees to bring down the ripe nuts may or may not be needed, depending on the weather. If there are numerous rains the nuts fall readily, free of the husk. After picking up, the nuts are thoroughly machine-washed and then dried in dryers. As time goes on commercial or cooperative dryers handle an increasingly large part of the crop. The nuts are then bleached, graded and packed according to the State grading laws and the demands of the market.

Filberts

Filbert growing has followed the same pattern of development as did walnut growing, except that it was two or three decades later in starting and, when once started, proceeded at a much more rapid rate. While walnut planting has nearly ceased for 15 years, filbert planting has been heavy, restricted in recent years only by the lack of availability of nursery stock.

In 1929 there was recorded a yield of 200 tons and in 1946 it was 8,950 tons. In 1929 the value of the crop was $60,000, while for the three years 1943, 1944 and 1945 the average farm value was $3,286,000 annually.

Filbert trees are planted at the rate of about 70 trees to the acre. Culture and care are essentially the same as for other nut trees. One or two spray applications are becoming necessary each summer to control the filbert worm. Nuts are picked from the ground. In the case of the Barcelona, the main variety in Oregon, the nuts fall free from the husk. In the case of DuChilly, the dominant variety in Washington, the nuts must be threshed out of the husks. As with walnuts, the nuts are washed after picking, then dried, bleached, graded and packed. All grading and packing is done in centralized plants. As yet, most of the nuts are sold in the shell, but the percentage of the crop that is cracked and sold as kernels is increasing rapidly. A few of the kernels in the past have been toasted, salted and sold in small packages. Such an outlet is again assuming importance.

The six-million-dollar walnut and filbert industry is contained in the area of Oregon and Washington that is west of the Cascade mountains and east of the Coast Range mountains of Oregon and the corresponding territory in Washington. Ninety per cent of the income flows into the Willamette Valley of Oregon. Walnut growing is carried on in a very small way in southern Oregon, and extends also into the southern counties of Washington. Filbert growing is on a limited scale in the Umpqua Valley in Oregon just south of the Willamette Valley. In Washington the filbert growing industry extends to the northern boundary and over into British Columbia.

With a small population in the Pacific Northwest, only a small part of the crop is consumed in this area; of necessity the rest must be disposed of in the large centers of population in the eastern part of the United States.

East of the Cascade mountains in Oregon there is no commercial industry in either walnut or filbert growing due to low winter temperatures and high temperatures in summer.

Attempts in Oregon to grow other tree nuts as they are grown commercially in other parts of the country have failed. Pecan trees grow well but have failed to bear. Production of almonds is very irregular, and the trees are so subject to disease that they are usually very short lived.

Red Squill—*Most Specific of the Raticides*

This bulb of the lily family is extremely poisonous to mice and rats but relatively non-toxic to domestic animals and humans.

D. GLEN CRABTREE

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Introduction

ALTHOUGH the lethal effect of red squill bulbs on rats has been known and employed since ancient times to combat these pests by the peoples inhabiting the lands bordering the Mediterranean Sea, it has risen to prominence as a modern raticide only within the past 20 years. This was due largely to accelerated research on the utilization of red squill in rat control operations. In the United States steadily increasing amounts of this substance have been used in recent years, and renewed interest in red squill has been evidenced by practically all nations. The reason for this universal interest lies in the peculiar properties of red squill which render it the most specific of the raticides now available. Red squill, or squill, as it is commonly known, is toxic to and, when incorporated in suitable bait material, well accepted by rats, whereas domestic animals and humans find such a combination distasteful. In addition, squill powders, extracts and highly toxic concentrates of the active principles are strongly emetic in nature. Since rats cannot vomit they are unable to rid themselves of the squill, as do most pets and humans who readily vomit squill baits ingested accidentally. These two inherent characteristics coupled with the fact that squill is a slow-acting material makes it by far the safest of the lethal agents available to the general public for controlling rats.

The Plant

Red squill (*Urginea maritima* (L.) Baker), commonly referred to as the sea onion, is a plant belonging to the Liliaceae or lily family. It is native to countries bordering on the Mediterranean (Fig. 1) where the bulbs are harvested as a wild crop during the period of vegetative dormancy and usually just before flowering. The majority of the bulbs are sliced for drying, and the dried slices or "chips" exported, but a small portion of the bulbs gathered each year is exported for complete processing at the destination. Generally speaking, the potency of the bulbs varies with the locality from which they are gathered, the better quality for rat control purposes coming from Italy, Sardinia, Sicily and the Algerian Coast. The bulk of the squill imported into the United States during the last few years has originated from the latter source.

Mature red squill bulbs resemble a large onion in structure (Figs. 2–4). They are composed of overlapping fleshy scales, the outer being a reddish brown, and the interior varying in color from a light yellow to a deep purple. The scales of the central core are usually white. The bulbs of commerce ordinarily weigh from two to eight pounds, but some which have been grown for a period of years in this country have attained a weight of 20 pounds.

The plants produce their vegetative growth, consisting of deep green, blade-like leaves, in the fall and winter during the rainy season, and become devoid of foliage in the late spring and summer, a period when rainfall is practically nil in

the Mediterranean regions where squill abounds. During the period of dormancy when the plants are without leaves, usually in midsummer or early fall, a single stalk bearing a raceme of many flowers emerges and rapidly grows to a height of four or five feet (Fig. 2). The small white flowers have a narrow, light yellow-green stripe running longitudinally the length of the petal. A small band of flowers blooms each day progressively up the raceme; the number blossoming on any one day may vary from one or two up to as many as 50 or more. The fruit is a three-celled capsule with flat, black, slightly winged seeds having a thin, fragile shell. Individual seeds were found, on the average, to weigh about two milligrams, and when hand pollinated, one flower stalk produced approximately 4,800 seed.

In addition to the red squill, a white variety is also available commercially. White squill is used in human medicine as a heart tonic and nauseant expectorant. These two varieties apparently present no botanical differences. Although microscopical examination of powders prepared from red squill may reveal cells containing red pigment, and those from white squill usually lack them, the biological reactions of these substances are the most reliable basis of differentiation.

Whereas red squill exhibits the same general properties as white squill, in addition, it contains toxic glycosidal compounds which are generally referred to as the "rat-killing principles". In 1942 two Swiss chemists reported the isolation of the "rat-killing principle" of red squill in crystalline form. The compound scilliroside isolated by these workers (1) was found to contain glucose, and its extreme toxicity to rats is emphasized by the fact that the average lethal dose of the crystals for male rats is only seven-tenths of a milligram per kilogram of body weight. Thus, it will be noted, the toxic principles of red squill, in their purified form, are among the most potent of rat poisons. Whether scilliroside is the only compound in squill that is toxic to rats, remains to be determined.

The tissue of both squills contains minute needle-like crystals or raphides of calcium oxalate usually embedded in mucilage. These crystals are essentially non-toxic but are a factor in the nettle-like irritation which squill powders cause when they come into contact with the skin or mucous membranes. The irritation caused by squill preparations no

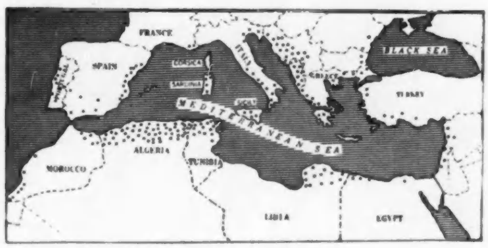


FIG. 1. Geographical distribution of red squill.

doubt contributes to the objectionable taste of squill baits which is evidenced by most animals except rats and mice. This acrid taste together with its slow toxicological action and its emetic nature combine to render red squill comparatively harmless to domestic stock, pets and humans.

Preparation and Toxicity

Since crude red squill powder, the ordinary article of commerce, is prepared by merely drying slices of red squill bulbs which may come from a number of sources, great variations in toxicity are encountered when different lots of powder are tested biologically. Indeed, the toxicity of individual bulbs harvested simultaneously from the same region and indistinguishable by visual inspection were found to vary in all degrees from highly potent to impotent. A consider-

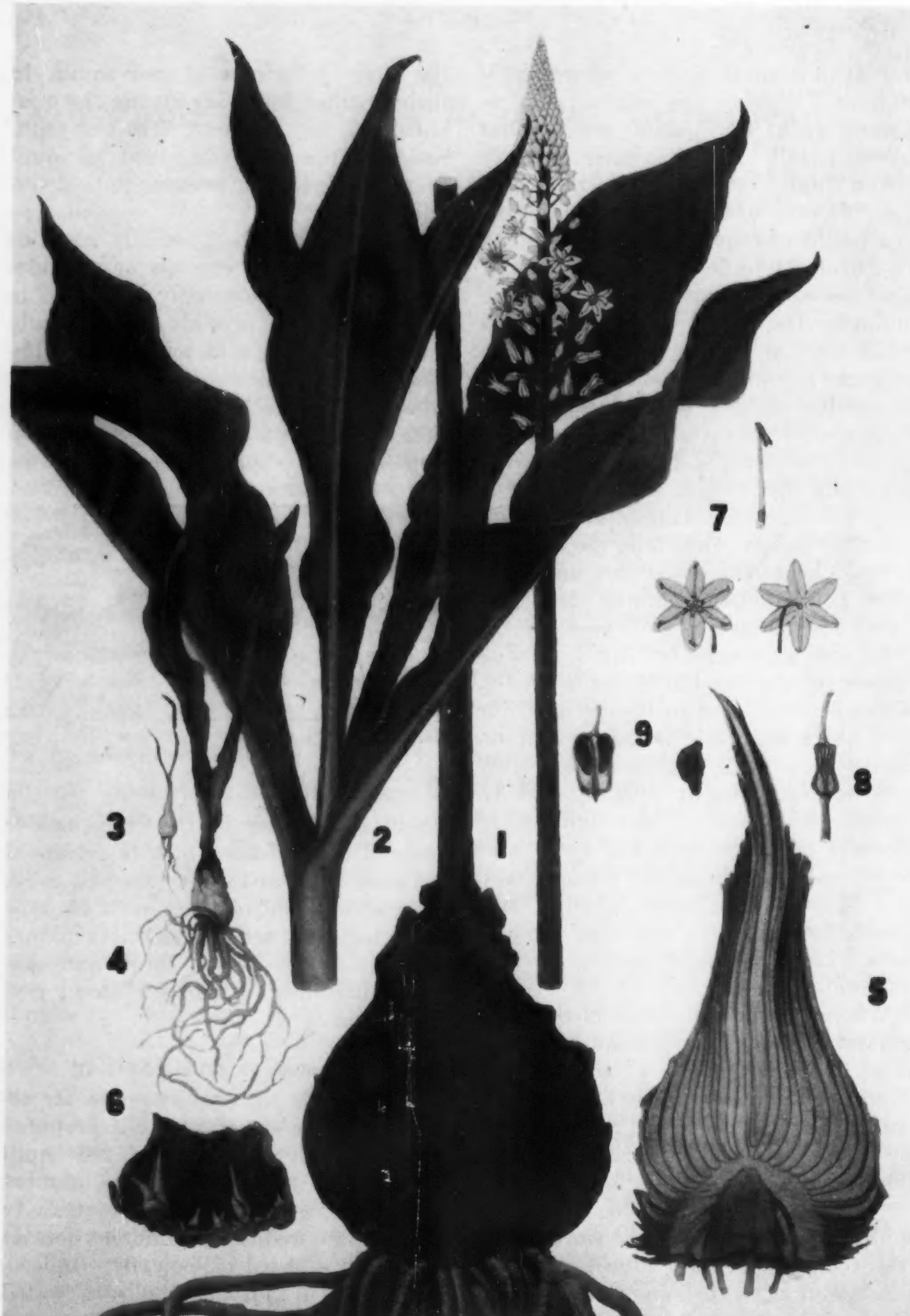


FIG. 2. Essential vegetative features of red squill. (From a water color plate by Ida Hrubesky Pemberton, Denver, Colorado.) 1. Mature red squill bulb with flower stalk. 2. Leaves. 3. Year old seedling. 4. Two-year-old seedling. 5. Longitudinal section through the center of mature bulb. 6. Leaf scale after planting in sand bed, showing asexual origin of small bulblets along the basal edge. 7. Stamen and flowers. 8. Pistil and ovary. 9. Seed pod and seed. Sections 7, 8 and 9 are drawn to a larger scale than the other elements in this plate.

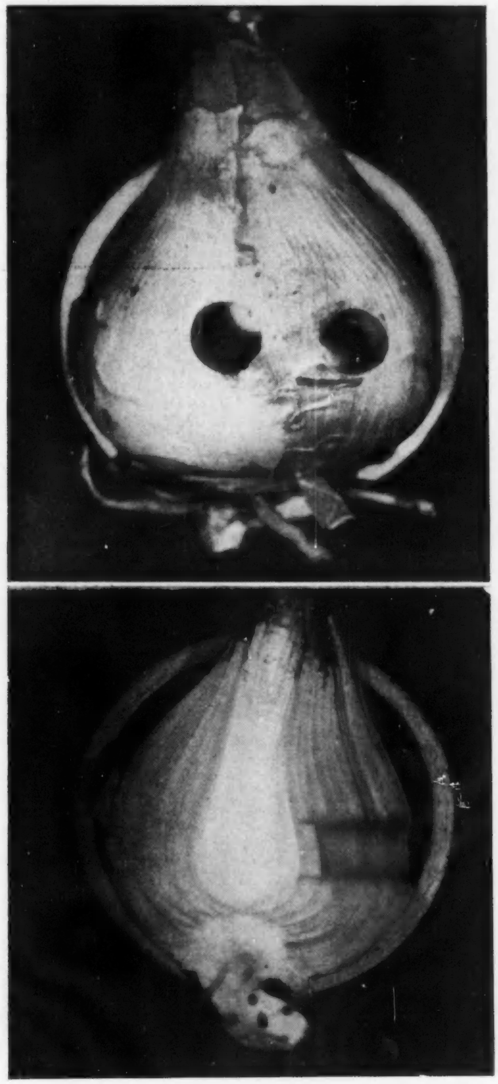
able portion of the bulbs from any one area apparently fall into the latter category. From this it is apparent that only a small percentage of highly toxic bulbs are ordinarily incorporated into crude commercial powders. As a result some crude powders tested in recent years were found to have a toxicity such that 400 mg./kg. sufficed to kill male rats, while others required as much as 3,000 milligrams of powder per kilogram of body weight to produce death. Translated into grains per pound the above dosages become approximately 2.8 and 21, respectively. White squill has failed to kill rats when administered in doses as high as 5,000 mg./kg., and for all practical purposes is considered to be non-toxic to rats.

As the male rat is much more resistant to the action of squill than the female, the former is most commonly used for testing squill products. In accurate bioassays, calculation of the dosage mortality curve (3) is the usual method employed to determine the LD 50% point.

Several factors are known or suspected to influence squill bioassays: the strain of albino rats employed, the age of the test animal, previous diet fed and the altitude at which the bioassay is conducted. Of the factors mentioned, the strain of rat used is probably the greatest single cause of the variable results often reported when identical samples are assayed at different laboratories.

Propagation of Red Squill Bulbs in the United States

During the past six years the Wildlife Research Laboratory at Denver, in cooperation with the Bureau of Plant Industry, Soils, and Agricultural Engineering, Department of Agriculture, has made experimental plantings of red squill bulbs in the regions of the United States where mild winter temperatures prevail. From several years observation of the progress made by bulbs planted in selected spots across the southern United States from Florida to California, it appears that red squill grows best in the coastal regions of southern Cali-



FIGS. 3 & 4. Method of plug sampling. The holes are filled with paraffin before the bulbs are replanted.

fornia from Camarillo south to Ensenada, Baja California, Mexico. It is in this area that the climatic pattern and rainfall parallels that of the Mediter-

ranean regions to which squill is native. The Foreign Economic Administration assisted in 1944 by importing 1,500 mature bulbs from Algeria for propagational studies in the western hemisphere. These, after being plug sampled (Figs. 3 and 4) at Denver for a toxicity determination of each bulb, were sent to Ensenada, Mexico, where they were grown under observation for two years (Fig. 6). In 1946 the bulk of the bulbs were transferred to the Torrey Pines Station of the Bureau of Plant Industry, Soils, and Agricultural Engineering near San Diego, California, where propagation studies will be continued. Efforts are being directed through selection and breeding experiments toward the development of a strain having a uniformly high toxicity and other characteristics suitable for domestic cultivation on a commercial scale. Propagation is effected by means of bulb cuttings and seed (Fig. 2). Unfortunately, several years are required to produce mature bulbs from seed or by the cutting method, and because of this fact red squill development will of necessity be a long term project.

FIG. 5. Root system developed in one season by a mature red squill bulb when grown in a large flower pot.

Standardization and Fortification of Red Squill

As the utilization of red squill in rat control increased, efforts to fill what in reality constituted an abnormal demand for this commodity led to the collection of squill from all available sources. Quality soon became of secondary importance, and the average potency of sun-dried chips and of bulbs reaching the United States fell to a point where it could no longer be used effectively as a rat control agent.

Faced with a huge supply of poor quality squill already on hand in the country and an accelerated need for rat control, the Denver Wildlife Research Laboratory of the Fish and Wildlife Service investigated the problem at some length and developed a method for fortifying this type of squill with suitable extracts prepared from a portion of the same low grade material to a level of toxicity at which it could be employed against rats with efficient results. The method (2) consists essentially of an intermittent, counter-current extraction of powdered red squill with an 80% ethyl-

alcohol-water solution. Three extraction cells were incorporated into the extraction process and the solvent routed through the system in such a manner that each charge of squill was extracted five times. The final extract was concentrated in vacuo and proved to be several times more toxic on a dry weight basis than that accomplished by merely extracting a single batch of powder with five separate lots of fresh solvent. The extract obtained from the counter-current process, after concentration, is mixed with a predetermined amount of unextracted powder, the mixture dried at 80° C., and the dried squill "cake" then re-milled to a 20-mesh or finer powder. "Fortified" extracts can be prepared by merely diluting the concentrated extract with glycerine or any other suitable diluent to a desired toxicity level. Preservatives, *e.g.*, sodium benzoate and salicylic acid, are added in small quantities to fluid extracts to enhance their keeping qualities. Control of the process as well as determination of the toxicity of the final product is carried out by bioassay procedures using male albino rats as test animals.

The fortified product, powder or extract, retains all of the safety factors present in crude squill powders and, when fortified to a satisfactorily toxic level, will, when properly used, effect an efficient degree of rat control.

As demonstrated by actual operations, the more toxic the squill preparation used in the baits the greater the degree of control attained. In this respect, squill powders and extracts having an LD 50% for the male rats (lethal dose killing 50% of the test animals) of 600 mg./kg. have given satisfactory control when incorporated into highly attractive bait materials which were then carefully exposed. However, a 400 mg./kg. squill is a more desirable product in that the animal ingests a lethal dose upon consuming less bait than is required when a less toxic squill is employed. An added advantage in using the more potent squills lies in the fact that less attractive and generally less expensive bait materials can be used with this type of product.

Effect on Rats

Rats that have eaten a fatal dose of red squill exhibit a train of symptoms which indicate that it acts primarily on

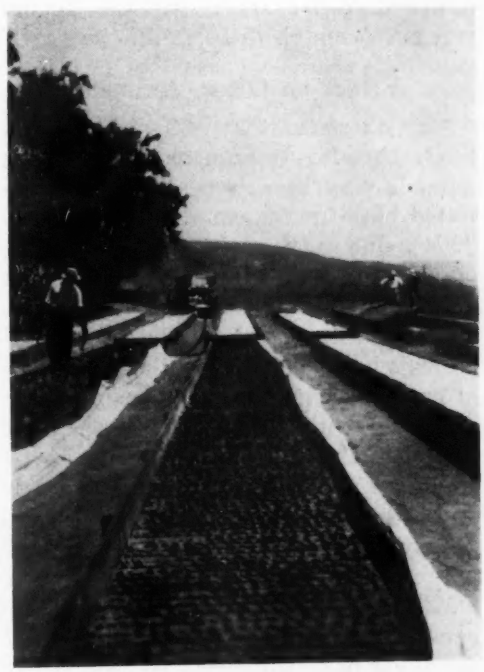


FIG. 6. Sand beds for propagation of red squill by cuttings. This work was conducted by the Foreign Economic Administration near Ensenada, Baja California, Mexico.

the central nervous system. Within one or two hours after the ingestion of a killing dose the rat becomes lethargic and shows signs of irritation about the mouth and nose. After a short period tremors and paralysis of the hind legs appear. The paralysis progressively involves the trunk and forelegs, and the breathing becomes labored. At this stage intermittent convulsions in which the rat rolls over and over or rotates

on its longitudinal axis provide the most characteristic symptom of red squill poisoning. During the convulsive phase, a rat, quietly resting, may be thrown into a series of gyrations by merely disturbing the cage. The convulsive period may last from a few hours up to several days and is followed by prostration. Death results largely from respiratory failure. Upon post-mortem examination there is pronounced irritation of the upper digestive tract, but this is not extensive enough to be fatal.

Effect on Other Animals

The statement that red squill is relatively harmless to humans and domestic animals has been repeatedly substantiated both in this country and abroad. This is due in the main to the reluctance of animals other than the rat or house mouse to eat baits containing red squill. This has been found to hold even when animals have been kept under conditions of enforced hunger and the regular diet combined with red squill was the only food available.

Horses and ruminants, such as cattle and sheep, as a general rule, almost completely refuse food items contaminated with red squill. The size of these animals affords them additional protection because of the large amount of a 10% red squill rat bait that would be required to produce a toxic reaction.

Pigs normally show a marked aversion to red squill, and it is quite unlikely that hogs will voluntarily eat enough of a red squill rat bait to provide a lethal dose. One-half pound or more of a red squill rat bait would be required to kill an adult hog.

Dogs and cats, particularly the latter, consistently refuse red squill baits, and if eaten profuse vomiting usually is the only consequence.

Pigeons were found to refuse food containing red squill, and crop vomiting was the only response when red squill was injected directly into the crop.

Chickens proved very resistant to the action of red squill, although they readily eat red squill when it is combined with their food. In this regard, adult chickens have been maintained in good health for long periods when 10% red squill was added to the daily ration. It is unlikely that baby chicks will eat enough red squill bait to cause injury.

Field rodents, such as the prairie dog, pocket gopher or woodchuck, refused to eat toxic quantities of red squill baits.

House mice do not hesitate to eat red squill baits, but due to the feeding habits of this animal an effective degree of control through the use of red squill is not often attained. The house mouse tends to feed frequently and usually takes only small amounts of food at each feeding. In view of this peculiarity, it is probable that sufficient time may elapse between feedings to allow the initial symptoms of red squill to develop and thus prevent the consumption of a lethal dose of bait through subsequent feedings.

Under conditions of forced feeding or stomach tube administration, it has been demonstrated that red squill is about equally as toxic to most animals as it is for the rat. Protection from red squill is afforded by the marked unwillingness of most animals to accept food containing it, by its producing vomiting in those animals which are able to vomit and by its being more or less non-toxic to some forms, for example, poultry. Since the total amount of red squill necessary to produce toxic symptoms or death in any animal varies with its weight, the larger animals find additional protection in that relatively large quantities of a 10% red squill rat bait must be ingested to cause serious effects.

Below are some of the approximate lethal doses of red squill which have been listed in the literature or which were obtained through forced feeding or stomach tube administration of red squill to various farm animals. For comparative

purposes the toxicity of the squill used is also given for rats:

ANIMAL	LETHAL DOSE IN MILLIGRAMS OF RED SQUILL PER KILOGRAM OF BODY WEIGHT
Cattle	200
Horses	200
Sheep	200
Pigs	200
Rats	200

Accidental ingestion of red squill rat baits by humans has occurred many times with vomiting the only discomfort encountered. As an experiment, one individual took 40 grains of red squill powder. Nausea and vomiting occurred within 15 minutes and no other symptoms developed.

Although red squill can be used about the home or farm with little danger to individuals or domestic stock, it must be remembered that if the baits are eaten or scattered by animals other than those for which they were intended, they may no longer be available for killing rats. It is also possible that under some conditions which have not as yet been fully investigated the irritant qualities of red squill may prove hazardous to animals not in good health. For the above reasons it is obvious that insofar as possible, red squill baits should be placed in such a manner that animals other than rats and mice will not have ready access to them.

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Utilization Abstracts

Jojoba. In the desert regions of the southwestern United States there is a shrubby plant, up to four feet tall and known as goat nut or jojoba (pronounced "hohoba"), that has possibilities as a commercial source of oil. The seeds contain about 48% of oil which has been used locally as a hair tonic, and an old Spanish account of 1789 attributes medicinal virtues to the plant, holding it to be a cure for wounds and a remedy for cancer. The acorn-like fruits have long been eaten by Indians and others, and cattle are fond of both fruits and leaves.

In 1933 it was discovered that the so-called oil in jojoba seeds is a liquid wax, as is sperm oil; all other known seeds contain fatty or glyceride oils. Patents have been issued on a rubber-like substance made from the oil; on use of the oil in shortening and other food products to delay their becoming rancid; and on use of it in printer's ink and as a lubricant for delicate instruments. Application for a patent was made about six years ago to cover the hydrogenated wax which is suitable for candles, since candles made from it do not melt before being used, even in the hot Arizona climate. In hardness jojoba ranks next to carnaúba wax and competes with it in some uses.

After the oil is removed from the seed the residue is suitable for stock feed and can be used also in plastics. A beverage has been made from the ground and roasted seed, and sometimes the fruits are eaten directly from the bushes.

In the spring of 1946 at least one ambitious commercial planting of jojoba was undertaken in the Southwest, but before the end of the year it was abandoned to a large extent. (*Margaret Douglas, Jour. N. Y. Bot. Garden 48: 29. 1947*).

Botanical Drugs—*A Brief Review of the Industry with Comments on Recent Developments*

Old-World sources of botanical drugs are still foremost, despite attempts during the two World Wars to develop American sources of Digitalis, Juniper berries, African peppers, Spearmint, Peppermint, Belladonna, Rhubarb root, Arnica flowers, Stramonium, Chamomile flowers and Fennel seed.

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S. B. Penick & Company, New York, N. Y.

Early History

THE history of the crude drug industry, both the commercial and technical aspects, probably began with the first barter arrangements between an ailing clan member and the corner witch doctor.

The earliest graphic records contain references to plants being cultivated or collected for use in medicine. A few hundred drugs were known to the Assyrians in 2500 B.C., and the famous "Papyrus Ebers" of 1600 B.C. records many Egyptian medicines and preparations then in established usage. Arabic writings dating from 1300 to 700 B.C. also contain numerous references to work in natural history, including medicinals, and the activities of Alexander the Great, naturalist, should be recalled as important contributions of the years around 320 B.C.

About 75 B.C. the outstanding work of the era was published—"De Materia Medica"—authored by Dioscorides, the renowned Greek physician. This work considered in detail several thousand botanicals and remained the authority for 15 centuries.

The next significant advances were made in comparatively recent times, being the works of Brunfels, Valerius, Cordus, Linné, and the fundamental studies in comparative plant anatomy by Schleiden.

Pharmaceutical botany and pharmacognosy, as we know them today, had their commencement in the writings of T. W. C. Martius and O. Berg, and later in the 1800's of Oesterle, Fluckiger, Moeller, Hanausek, Gilg, Tschirch, Hanbury, Greenish, Wallis and Von Mueller. These men were all continental Europeans with the exception of Greenish and Wallis who were British. The prominent early Americans active in this field were Millspaugh, and Bentley and Trimen. At the turn of the twentieth century, Rusby and Kraemer came to the foreground.

Concurrent with these scientific pursuits were important discoveries made in less learned circles. The first radiologists were the natives of the Belgian Congo who obtained seemingly miraculous cures for certain bodily ailments when they immersed themselves in selected wallows. Radium was later extracted from ores mined in these areas. The ancient Chinese healed suppurating wounds with green molds—penicillin in its infancy. And then there was the famous Shropshire housewife who sug-

gested the present medicinal usage of digitalis in heart disorders.

Witch doctors, folk-lore and old-wives-tales have all made valuable contributions to our present Materia Medica. Some of their remedies have fallen into disrepute, but a few valuable contributions remain.

As various explorations broadened the geographical horizons, new medicines were introduced into practice. First they were offered for sale from the ship's cargo, later imported by general merchants, and in the last few hundred years importers handling drugs exclusively came into prominence—first in Europe, then England and lastly in America.

At the same time, the apothecary was extending his operations to include merchandising wholesale quantities of drugs. A combination of these two fields was now a logical step. Most of the American companies started out as commission houses, small importers or, like ourselves, as collectors and merchants of domestic botanicals. It was a natural expansion to include imported drugs, insecticides, gums, spices, essential oils and resins as well as plant derivatives, such as glycosides, alkaloids, oleoresins and many other items of related origin.

A group of sales invoices from those times would show a peculiar assortment of transactions, such as carrying Ergot[1] from Europe for obstetrical use by a pharmaceutical manufacturer, gum tragacanth (*Astragalus* sp.) from western Asia and southeastern Europe for a manufacturer of printed textiles, cuttlefish bone (*Sepia officinalis* L.) for a pet shop to sharpen parrots' beaks, pyrethrum (*Chrysanthemum Leucanthemum* L.) from Africa for control of agricultural insect pests, juniper berries (*Juniperus communis* L.) from central Europe for a gin distiller, sage leaves (*Salvia officinalis* L.) from central Europe for the butcher, poppy seed (*Papaver somniferum* L. var. *nigrum* D.C.) from Holland for the baker, and gum olibanum (*Boswellia* sp.) from Arabia for the candlemaker.

[1] Ergot is the dried sclerotium of the fungus *Claviceps purpurea* (Fries) Tulasne developed on rye plants infested by it. See article on ergot in this issue.

Uses, Sources and Variety of Drugs

It is interesting to note that some officially recognized drugs find their greatest use in fields other than pharmacy or medicine.

Licorice root (*Glycyrrhiza* sp.) from southeastern Europe and the Occident, for instance, is used primarily by the tobacco industry, secondarily by confectioners and least of all in medicine. As for soap bark (*Quillaja Saponaria* Molina) from Peru and Chile, every time a pound finds its way into a pharmaceutical, a ton goes to industrial users in many lines, for example, the manufacture of fire-extinguishing solutions. And karaya gum (*Sterculia* sp.) from Persia is vastly more important to the food industries than it is to pharmaceuticals. But before the reader is misled, we hasten to say that the majority of drug sales has a very definite leaning towards the side of medicine. There is hardly a dicotyledonous plant family in Engler & Gilg's list which does not contribute to the Materia Medica. Every plant part is represented in one or another drug, and with some plants, various parts or a combination of parts are used. Roots, stems, leaves, flowers, fruits, seeds, rhizomes, bulbs, barks, flower buds, pollen, all these and other organs or tissues are to be found.

Geographically speaking, the world is our garden, both the land and water areas—cod-liver oil for vitamin nutrition from the Arctic, buchu leaves (*Barosma* sp.) for urinary disorders from Capetown, Moroccan coriander seed (*Coriandrum sativum* L.) for flavoring purposes,

and kava kava root (*Piper methysticum* Foster) for its diuretic qualities from opposite points on the equator.

The extremes of time yield their valued products: Diatomaceous earth for filtering purposes is obtained from deposits several million years old, and sweet-scented Balm of Gilead buds (*Populus candicans* Aiton, *P. Tacamahacca* Miller), as an ingredient in cough medicines, are gathered in the early spring before they start to open.

There are big plants and little ones: eucalyptus (*E. globulus* Lab.) the oil of which possess a variety of pharmaceutical properties, and drosera (*D. rotundifolia* L., *D. anglica* Hud., *D. longifolia* L.) used as an expectorant in bronchitis and coughs; big parts and little ones: quassia logs (*Picrasma excelsa* (Swartz) Planchon), the infusion of which serves as a bitter tonic; and the spores of lycopodium (*L. clavatum*), used as a protective dusting powder for pills and in fireworks.

Some items, *e.g.*, chamomile flowers (*Matricaria Chamomilla* L.), of domestic and European production, a tonic and gastric stimulant, require little handling at their source of origin other than drying and packing for shipment. On arrival at New York such medicinals are sold mostly in original packing, although some quantities are repacked into considerably smaller units, such as five pounds, or as little as one ounce.

Digitalis leaves (*D. purpurea* L.), also of domestic and European production, require expert harvesting, drying and special packaging to insure retention of

FIG. 1. A scene in the mountains of North Carolina, near Asheville, where considerable botanical material is collected for processing in the drug industry.

maximum potency and to comply with official standards.

Senna pods (*Cassia Senna* L., *Cassia angustifolia* Vahl.), from the Sudan and India, for use as a purgative, and juniper berries require hand-picking to produce top quality material. Cardamon fruits (*Elettaria Cardamomum* Maton) for flavoring, from India, must be graded and usually are bleached before packing. Numerous other items receive some degree of grading, picking, sorting and cleaning, with much of the work done by hand or by the use of rather primitive machines.

Some items require a curing process to prepare them for market. Gentian root (*Gentiana lutea* L.) from France and Spain for use in tonics, and kola nuts (*Cola nitida* and other sp.) from Jamaica, Nigeria and Liberia for their stimulating quality are good examples. Gentian is a well established simple bitter—one of the best. The roots are collected from plants two to five years old, and more. These roots (and rhizomes) are gathered into mounds and allowed to dry and ferment slowly. The internal color slowly changes from white to medium brown, and the characteristic odor and taste develop.

Kola nuts are the fleshy cotyledons of the seed. When fresh, their internal color is comparatively light, but on exposure to light and air, the color gradually darkens, as does a slice of fresh apple, until it becomes a dark reddish-brown. The dried kolas are quite hard and tough.

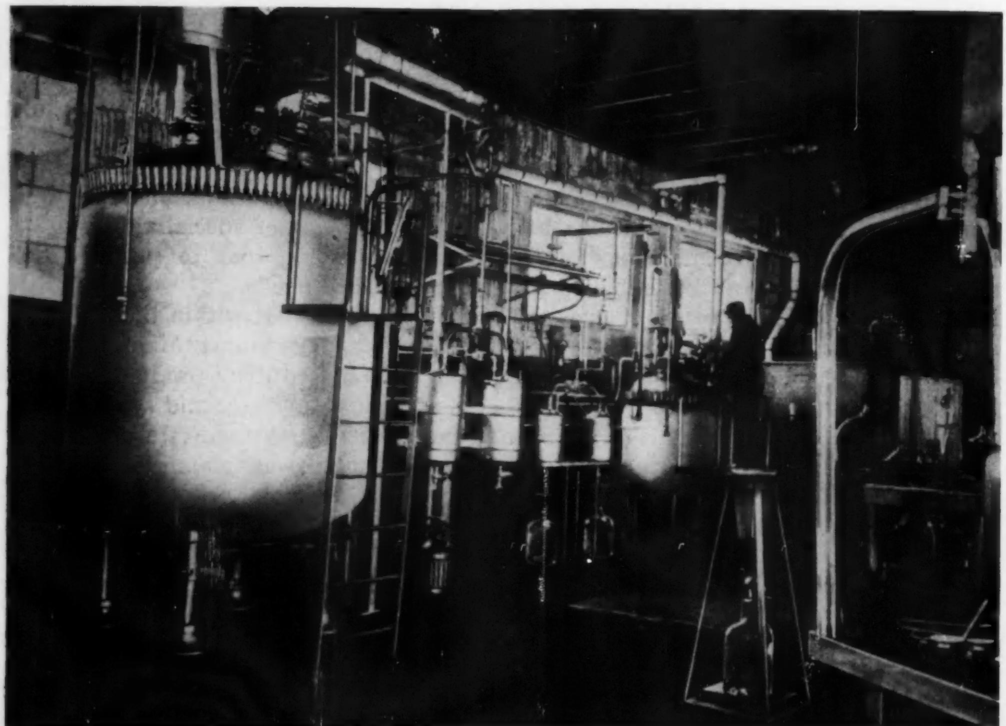
Most of the manufacturing is carried out with the crude materials after arrival in the United States, one very good reason being that milled drugs are dutiable at 10% ad-valorem, whereas most crudes are free of duty. Another reason is the lack of special machinery and skilled labor in the producing areas, with the resultant lack of economical operation and, even more important, the absence of stringent quality control in foreign areas.

Practically all drugs require some milling on arrival to make them ready for the manufacturer or other consumer. Sifting, reconditioning, grinding, cutting, powdering, grading, blending and many other types of specialized machine processes are required to produce the varied finished goods.

Although it is not within the province of the industry to manufacture such classes of finished drug products as tablets and pills, tinctures and syrups, it is often of service to facilitate operations for pharmaceutical manufacturers by changing the crude drug into a more readily utilizable product such as an oleoresin or an extract. Extracts represent the total soluble constituents of the original drug and are produced by maceration, percolation, filtration and evaporation to a consistency resembling that of honey, or to a solid which is powdered before packaging. Kola nuts are frequently processed in this manner. Oleoresins of capsicum (*C. frutescens* L.), from Louisiana, Zanzibar, Mombasa, Nyassaland and Sierra Leone for use as a stimulant and condiment, are mixtures of the volatile oils and the soluble resins in the crude. They are obtained by percolation with ethyl alcohol or some similar solvent, filtration and evaporation. As with extracts, low heat and a high vacuum facilitate the evaporation process.

Concentrations, another type of product, are manufactured by precipitating out of an alcoholic solution mixtures of certain active resinous principles of an indefinite nature, as with leptandra (*Veronica virginica* L.) of the Southern Appalachians, from which leptandrin is made for use as a cathartic and emetic. This is accomplished by pouring a concentrated solution into water, then separating and drying the precipitate.

Jalap root (*Exogonium purga* Wen-



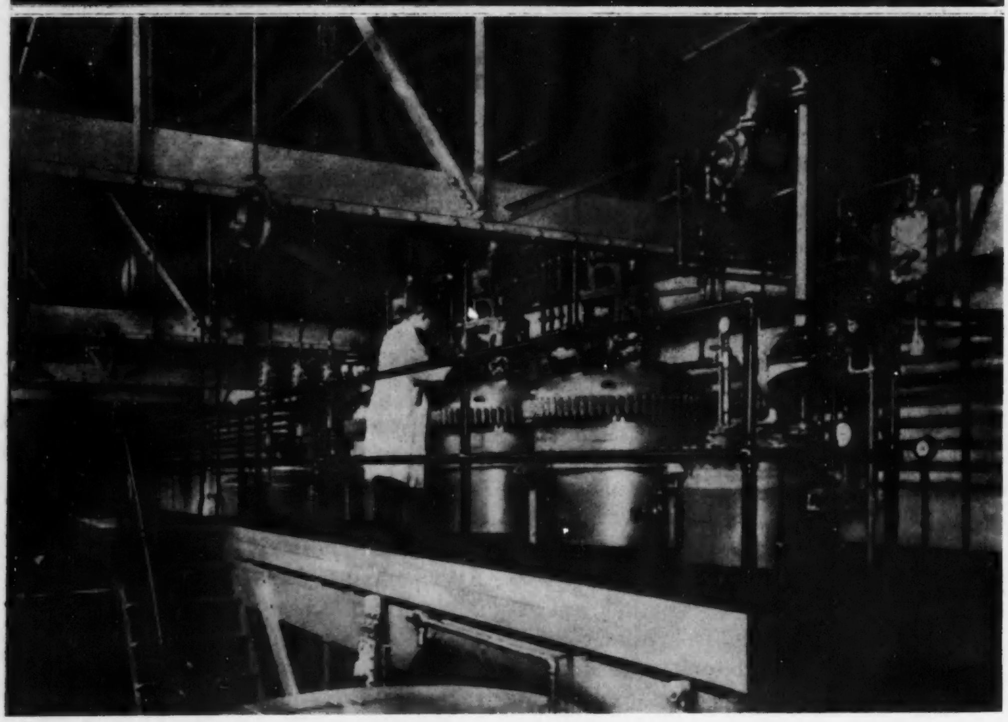


FIG. 2 (*Upper*). A portion of the equipment necessary for modern high-fractionation processing of botanicals. FIG. 3 (*Lower*). Some of the modern equipment employed in alkaloid-finishing operations of botanicals.

deroth) Bentham from Mexico for cathartic use and other plants are extracted of their resins in a manner similar to the production of oleoresins.

When only one active principle is desired, more delicate operations are in order. Various members of the Solanaceae (*Hyoscyamus muticus* L., *Datura Metel* L.), for instance, are granulated, extracted by means of immiscible solvents, evaporated and re-extracted with a volatile solvent to yield such valuable

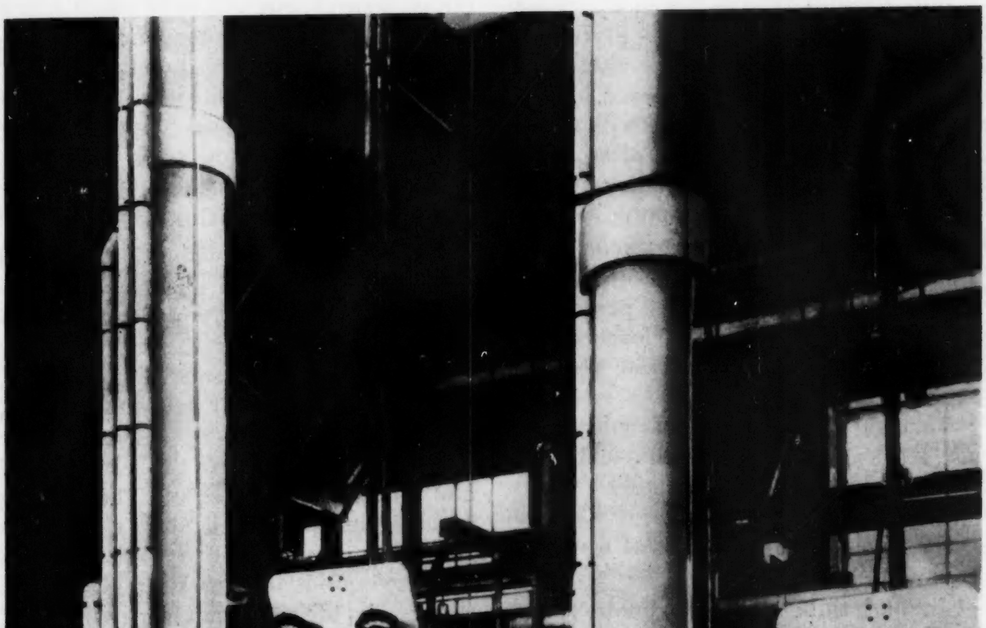


FIG. 4. Other equipment in a high-fractionation department.

alkaloids as atropine and scopolamine, which are crystallized and recrystallized by means of appropriate solvents. If an acid salt is desired, such as the sulfate, the properly acidulated aqueous solution is crystallized.

It is difficult to give a general procedure for the manufacture of glycosides, as the method varies with the stability of the product. Some are obtained by precipitating an aqueous extract with tannic acid, removing the precipitant as an insoluble metal salt and crystallizing from the purified aqueous solution.

On the surface these operations might appear to be relatively simple, but in actual practice the various procedures become an art and a science learned only after long apprenticeship and years of experience.

Various aromatic plants and plant parts are steam-distilled to yield their valuable essential oils. Usually redistillation and/or fractionation is a necessary step in the production of an oil of high quality.

As one thing leads to another, the manufacture of synthetic perfume and flavoring materials follows, as does the production of heavy organic and metal-organic compounds. Many so-called "synthetic aromatics" are derived from chemically related crude materials of natural origin. It becomes evident that although the crude drug industry is mainly concerned with botanicals, several other classes of items are dealt with. These other groups are mentioned occasionally in this article in order to leave a more accurate impression.

Rutin is another item of interesting manufacture which is currently obtained from green buckwheat. This chemical, regarded as a vitamin-P analog, has recently enjoyed an upsurge of popularity in medical circles for treating capillary fragility.

From the soil we get *Bacillus brevis* which is used in cultures to produce tyrothrycin, recently discovered as being of considerable value as an antibiotic. Many botanicals are presently being screened for their possible value as antibiotics.

By these, and other processes, a 300-pound bale of leaves is reduced to a few ounces of alkaloid; a ton of flowers becomes a small flask of oil; or the pungent capsicum is concentrated in potency to the tongue-tingling peak of "red dynamite".

Drug Identification and Evaluation

Identification and evaluation of crude drugs constitute both an art and a science. Many of the finer points of evaluation are learned only through long experience, as is the case with tea-tasters, perfumers and similar artisans. Drugs, once identity has been established, are judged solely according to their physical and chemical analyses, and the services of chemists, pharmacognocists, pharmacologists and physicists are all necessary in carrying out this work.

Primary identification is usually based on botanical, or more specifically, pharmacognostical methods. There is no such practice as "keying-out" a root or a bark. Identification is based on visual and microscopical inspection, later to be checked by chemical and other means. This procedure is reliable whenever the item in question is reasonably well known and established, but if the root or bark, or other plant part, is a new item, purely botanical methods are employed, working from herbarium specimens.

Quality and purity are judged by these same methods plus chemical and microchemical tests, biological assays and examination by physical methods, employing such apparatus as the ultraviolet light.

Intentionally, or by accident, botanical drugs are subject to contamination, adulteration and substitution. As for

contamination, this is usually the result of ignorance or carelessness on the part of the producer or collector. Occasionally drugs become contaminated with foreign odors or flavors from other merchandise stored close by. Inclusion of more than the allowed percentages of foreign organic or inorganic matter is classed as adulteration. For example, 5% of stems are allowed in ipecac root (*Cephaelis acuminata* Karsten, *C. Ipecacuanha* (Brotero) A. Richard) from Brazil and Central America for use as an emetic, and inclusion of a higher percentage would be regarded as adulteration. The borderline between contamination and adulteration is rather finely drawn, especially in legal circles. If the adulteration is intentional, the unscrupulous producer usually resorts to the cheapest and most convenient material at hand. Odd lots of such items from the fields or warehouses, or any other substance that the seller can introduce, are utilized if the seller believes there is little chance of detection. Rocks, stones and scrap iron are now less frequently encountered, but occasional attempts are made with an embarrassing lack of success. Experience shows there to be no such thing as a "common" adulterant if the introduction is intentional. Substitution of some other item, in whole or in part, occasionally happens. Here again, ignorance of the shipper is usually the cause. Several drugs are subject to substitution whenever easily mistaken unwanted plants of similar appearance grow in the same area with the proper species.

Domestic Cultivation and Gathering

The botanical drug industry was both handicapped and stimulated by the two World Wars. Because certain plants are indigenous to relatively small areas, or because only those obtained from certain areas are of medicinal value, or because it is economically practical to produce or collect only from certain areas, most nations are, comparatively speaking, pitiably reliant on other nations for their requirements of crude drugs. During World War I the Americas sought a solution to this situation with varying degrees of permanency and success.

Cinchona was indeed a proverbial "thorn", as will be seen later, and it was not until the second war that the United States had any degree of independence from the production of this material in the East Indies.

Before the close of World War I certain shortages in drugs, other than that of cinchona, were lessened by domestic cultivations. African peppers were grown in South Carolina, spearmint (*Mentha spicata* L.) and peppermint (*Mentha piperita* L.) in Wisconsin and belladonna (*Atropa Belladonna* L.) in California to a limited extent, while digitalis was collected from wild growth in Washington and Oregon.

All these efforts had their basic obstacles. Food crops were of paramount importance throughout the world. High labor costs in the States were a serious economic handicap to most projects. Propagating material was difficult if not impossible to obtain. Natural habitats were difficult to satisfactorily duplicate. Perennial herbs and woody plants were slow to yield a harvest.

When World War II materialized there was a body of experience and a nucleus of former productions. There was the realization that much work had to be done and that several years would pass before the opening up of former sources of supply. Here, time prodded with an urgency and an ominous warning as to the consequences of shortages in critical materials.

When the probable geographical extent of the war and its possible duration became apparent, considerable effort was expended to plan some relief from the

inevitable scarcities. After the expenditure of concerted effort by field men, two important domestic collections were started, digitalis leaves and juniper berries.

Digitalis was formerly imported in quantity from southern Europe, especially the Balkans. It is not uncommon in other countries also, and it is well known in many flower gardens as the popular foxglove. Fortunately it grows rather profusely in the foothills of Washington and Oregon. Although it meant higher prices, due to the cost of domestic labor, sizable quantities were collected in these two States.

Not being satisfied with the uneven quality and the mounting costs, the domestic cultivation of this highly valuable plant was undertaken. The first real crop of digitalis was harvested in 1946. Because the plant lends itself to mechanized agriculture, and because of the steady demand, its cultivation will probably be continued.

Disregarding the economic risks being taken, careful plans for greatly increased production were laid for 1942. Acreage was contracted for in Pennsylvania, New Jersey, Ohio, Tennessee, Wisconsin and Virginia. Greenhouse space was obtained after much effort from nine nurseries. Five million belladonna seedlings were grown, transplanted twice by hand and rushed to 216 farmers for setting out in the fields. Special dryers were built, each of which could efficiently dry two tons of leaves every 24 hours.

Pennsylvania and Wisconsin had the best yields. The work continues and the valuable records will be available if ever again the project has to be resumed.

The following summary of yields and assays for the belladonna leaf crops is of interest. It should be borne in mind that the U. S. Pharmacopoeia XIII requires a minimum of 0.3% total alkaloids.

YIELDS AND ASSAYS OF DOMESTIC BELLADONA

STATE	NO. OF FARMERS	AVERAGE YIELD PER ACRE	PERCENTAGE OF TOTAL ALKALOIDS		
			LOWEST ASSAY	HIGHEST ASSAY	AVERAGE ASSAY
New Jersey	1	530 lbs.	.43%	.52%	.47%
Ohio	30	309 "	.47	.48	.475
Pennsylvania	73	787 "	.34	.64	.52
Tennessee	30	162 "	.44	.57	.53
Virginia	26	207 "	.52	.55	.54
Wisconsin	56	970 "	.38	.60	.46

Belladonna was placed in cultivation at an even earlier date, there being no accessible foreign areas where it could be collected in sufficient amount. During the first World War a small quantity was grown in California, but not on a scale or with success comparable to operations during the more recent war. In cooperation with the Bureau of Plant Industry, a quantity of seed was procured. Private negotiations with Switzerland yielded a few more pounds, and in 1941 the first crop was harvested. It was disappointingly poor.

Attempts to grow rhubarb roots (*Rheum officinale* Baillon, *R. palmatum* L.) for laxative use in the United States was disappointing. The plant requires the steady, slow development and growth conditions of central China to produce a large, compact, medicinally effective root and rhizome.

The increasing shortage of juniper berries was taken care of by extensive collections, principally by farmers in the State of Maine. At first the individual lots were small and of uneven quality, and every conceivable type of packing was used, including old pillow slips. A

good bit of sifting and grading had to be done on these early lots. But as the collectors gained experience, the quality soon improved to a point where the finished product compared quite favorably with berries formerly imported from southern Europe.

Arnica flowers (*A. Montana* L.) for treating bruises and sprains presented a somewhat different problem. The European Alps are the usual commercial source. This species of *Arnica* is not found growing in America nor is it a practical crop for cultivation. Research revealed that several species native to the western United States were acceptable in medicine, and some of them were made official in Supplements of the National Formulary VII and in the National Formulary VIII, namely, *A. fulgens* Pursh, *A. sororia* Greene and *A. cordifolia* Hooker. These species grow quite profusely in the alpine meadows of the Rocky Mountains, especially in Colorado. Domestic collection was initiated with success and continues in view of the shortage of acceptable qualities from Europe. Furthermore, the domestic species are not plagued by infestations of *Trypeta arnicivora.* In this and some other respects, such as cleanliness, the American flower is superior to the European item.

On the West Coast several firms in that area produced relatively small but very welcome quantities of agar from the seaweeds (Rhodophyceae) of southern California and the Pacific coast of Mexico. More detailed information on this and related marine products appears in an excellent article in the first issue of Economic Botany.

New Activities in Foreign Areas

In Argentina there were extensive cultivations of many botanicals, formerly obtained from abroad, such as stramonium (*Datura Stramonium* L.), used chiefly to relax the bronchial muscle in bronchial spasms of asthma, chamomile flowers and fennel seed (*Foeniculum vulgare* Miller) used as a stimulant and condiment.

Pyrethrum flowers were obtained in increasing quantities from cultivations in the Belgian Congo and Kenya Colony as the Japanese variety became unavailable. Some smaller quantities of poorer quality were produced in Brazil.

Peru was the source of many tons of cube roots (*Lonchocarpus Nicou* DC.), a source of the valuable insecticide rotenone formerly obtained in quantity from plants of the genus *Derris* in the East Indies. The necessary ground work was fostered by the United States and Peruvian governments and some private organizations in the United States.

Although constantly threatened by the impending closeness of the Japanese armies, India became an increasingly important source of supply. Rhubarb root from the foothills of the Himalayas did yoeman service until China resumed her shipments not so many months ago.

The Iberian Peninsula supplied urgent requirements of ergot, gentian root (*Gentiana lutea* L.), juniper berries, and orris root (*Iris florentina* L., *I. germanica* L., *I. pallida* Lamarck).

Before World War II most alkaloids and glucosides were imported from Europe, mostly from Germany and Switzerland, and to some extent from France. Only the opium alkaloids, strychnine, cocaine and the cinchona alkaloids were produced extensively in the United States.

With the coming of hostilities, broadened domestic production soon filled the gaps, and the following important phytochemicals, as well as many lesser known ones, were again available: atropine, homatropine, scopolamine, pilocarpine, emetine, totaquine, ouabain and digitonin.

Cinchona

Cinchona[2] alkaloids have always been of the utmost importance to the health of the civilian populations in tropical and sub-tropical climates, and are even more important to the health and fighting power of any army fighting in these regions. For the Allies this meant the entire Pacific and Asiatic theatres of war except Alaska.

Atabrine, a synthetic febrifuge, is indeed an important and highly valuable drug, but it alone does not offer a complete course of treatment for the malarias. The cinchona alkaloids are still highly valued and necessary in controlling this disease, and it is interesting to note that the common name "Bark", when used alone in the trade, refers to cinchona bark.

Before the recent war's outbreak, attempted cultivation of cinchona gained a measure of success in the Philippines. This good fortune was later to play an important part in providing seed for the experimental plots in Central and South America. Although it would take a good many years to grow a new forest of cinchona trees, nevertheless, the work was continued because of the possibility that the invaders might destroy the plantations in Java and in spite of the likelihood that the conflict might not last long enough to make the project worthwhile.

Meanwhile, totaquine was being developed. Totaquine is a standardized mixture of all the natural alkaloids of certain cinchona barks of Latin America origin. This product underwent an extensive laboratory and clinical investigation in 1930 and 1931. In 1931 the Malaria Commission of the League of Nations recommended the use of a standardized preparation of it, and in 1932 the product was recognized in the British Pharmacopoeia. By 1940, when supplies of cinchona bark from the Indies were cut off, totaquine was well established and had been produced since the previous year. All the bark imported from South and Central America, and the finished products, were subject to strict import control and allocation by our Government.

Several South American barks, other than those already noted, were also developed and found to be useful in the production of certain individual alkaloids as well as of totaquine derived up to that time from *C. succirubra*, *C. Ledgeriana* and *C. Calisaya*. These new sources included, in particular, *C. pitayensis*, *C. pubescens*, *Remijia pedunculata* and *Ladenbergia hookeriana*. The Foreign Economic Administration in cooperation with the industry and the governments of the Latin American countries were successful in developing these new sources.

At first, totaquine was to some degree nauseating because the amorphous quinoidine in it was not removed. Today, totaquine contains the four desirable alkaloids—quinine, quinidine, cinchonine, cinchonidine—with a medicinally inactive adjusting agent and can be considered, in every way, the therapeutic equivalent of quinine sulfate. All through the war, supplies were tight, but without totaquine the casualty lists would certainly have been more depressing.

Other War Time Difficulties

The passage of two wars has gradually changed the routing of foreign drugs through the trading centers of the world. Formerly these items were obtained to a considerable extent from the markets in London, Hamburg and Rotterdam. But now the United States obtains practically all of its supplies direct from the

[2] Cinchona bark is derived from *Cinchona succirubra* Pavon et Klotzsch, *C. Ledgeriana* (Howard) Moens et Trimen, *C. Calisaya* Weddell, and hybrids of these species and hybrids of these with other species of *Cinchona*.

various scattered origins. This was an inevitable and desirable outcome.

As for the primary sources of supply, the two wars had little effect in permanently changing them or replacing them. For Rhubarb Root we still look to China; for Black Pepper (*Piper nigrum* L.) we still rely on the Indies and India; Eastern Europe still supplies the best Valerian Root (*Valeriana officinalis* L.), and the best AgarAgar (*Gelidium* sp.), in quantity, will still be produced in Japan and Korea. A long list of examples could be given and there would be few exceptions to the generality.

The reasons for this condition are many, but to mention a few: It is no small matter to naturalize a species in a strange habitat, nor is there sufficient economic incentive to do so, in most instances, during times of peace. Not many drug crops lend themselves to successful cultivation. Only certain species of plants are acceptable in medicine, and most related species, however abundant elsewhere, are not acceptable or established.

It is appropriate to mention here another difficulty encountered when a replacement for a standard item is to be introduced, assuming that it is not radically different. Consider, for a moment, Black Pepper. This established item was famously scarce during the war. There are other reasonably abundant pungent species of *Piper* available in western Africa, but the housewife would display the same sales resistance to this new introduction as she did towards Brazilian maté when tea was becoming scarce. And if it be a drug, once the many months of preliminary work has been done, the physician must be introduced to it, educated in its varying manner of use and convinced of its value.

One must have a "Blue Ribbon Winner" before attempting to enter either of these last mentioned two contests. This is said with all due respect to both classes of persons mentioned.

Numerous examples of this situation occurred during the war. *Gentiana hederiana*, for example, is indigenous to the Peruvian and Chilean Andes, growing in remote areas, and it might possibly be acceptable as a replacement for European Gentian. But before it could be entered into commerce as such, considerable research would have to be done respecting its identification, availability, standardization, medicinal action and a few other factors. Experience shows this procedure to have been unrewarding except in a few selected instances.

In World War II the only successful substitutions were the temporary replacements of Chinese Rhubarb Root and European Valerian Root with the Indian species. In each case the replacing species was judged acceptable for the duration of the war only, and was listed in the National Formulary VII as such.

Aconite Root (*Aconitum Napellus* L.) was another scarce item during the war. The proper species is obtained from the central European Alps, and to a lesser extent from the Pyrenees. In former years rather extensive investigations have been made of the Japanese, Chinese and Indian aconites; most of these either were practically worthless in medicine or were possessed of markedly different and unacceptable activities. Therefore, what little root came from Spain during the war had to suffice. Every possible lead was followed up, with this and with other items, in the hope that a new source of an accepted species might be uncovered. Gratifying results were obtained only infrequently, but all the effort can still be considered as well spent.

A stubborn combination of economic and ecological factors is constantly present in replacing long acepted sources of drugs. They are seldom insurmountable, but frequently give rise only to some highly impractical solutions. An acceptable secondary area for the nat-

uralization of any plant species should fulfill the following requirements, in relation to the primary area, with a reasonable degree of acceptability, and this is quite a list to meet:

1. Geographically opposite in location on globe, season of growth and season of drastic climatic disturbances.
2. Similar climate.
3. Similar soil.
4. Low agricultural wage scale.
5. Geo-political stability.
6. Accessible transportation.

It might be interesting to note that drug collecting is a part-time seasonal activity of rural peoples. If a Tennessee mountaineer can get a high steady wage in a war-plant, such as Oak Ridge, there remains little incentive to collect Black Haw Bark (*Viburnum prunifolium* L., *V. rufidulum* Raf.). If a native of Aruba can earn an attractive salary as an unskilled laborer in the near-by oil refineries, why should he work in the fields producing Aloes (*Aloe Vera* L.) at a smaller figure? And so on throughout the world.

Ephedra (*Ephedra* sp.) is another interesting subject. This herb from China was long the crude source of ephedrine, but its alkaloid was also synthesized on an economical basis before the war. Now that supplies of the crude are again available, their prices have advanced about 300%. There is a body of opinion that synthetic ephedrine is inferior in efficacy to the mixed natural alkaloids, but the synthetic is now more widely employed.

Only a few medicinally active plant constituents have been synthesized economically, the usual low price of crude material being one reason, the technical difficulties of the synthesis the other main one. Crude drugs, however primitive they may appear beside a pure crystalline organic compound, will long occupy an important place in medicine. Indeed, some items which were for several years relegated to a dusty shelf are regaining popularity and value in both old and new fields of medicine. Every day new leads are obtained which point to the probable medicinal value of many plants, and botanical explorations are constantly turning up some new species of considerable value.

The author wishes to express his appreciation of the kindness of George M. Hocking, Ph.D., Professor of Pharmacognosy, University of Buffalo, in reading this paper.

Utilization Abstracts

Naranjilla. In Quito and Guayaquil, especially, but also elsewhere in Ecuador, the juice of naranjilla fruit, *Solanum quitoense*, constitutes a favorite foamy beverage, or "sorbete", nutritiously rich in vitamins, albumin, pepsin, lime, magnesium and phosphate. The spherical fruits, two inches in diameter, are tomato-like in growth, skin texture and internal structure, but are smaller, orange colored externally, greenish orange internally, and pubescent. In addition to being the source of an expressed beverage in Ecuador the fruits are also eaten raw or made into marmalade, pie or other culinary items.

Loss of flavor through pasteurization and addition of antifermentants in canning processes has so far hindered successful commercial export of the juice.

The naranjilla plant, a coarse succulent herb up to eight feet tall with leaves two feet long, is native to Ecuador, thriving best at elevations of 4,000 to 7,000 feet. It is also cultivated in Ecuador, as well as in southern Colombia where it is known as "lulu"; but in Peru the fruit seems to be unknown. The plants flower and fruit continuously, and thus are a continuous crop where cultivated.

Unsuccessful attempts have been made to produce the fruits in subtropical California and Florida. (*W. H. Hodge, Jour. N. Y. Botanical Garden 48: 155. 1947*).

Citrus Products—*A Quarter Century of Amazing Progress*

Highly specialized factories affiliated with the California Fruit Growers Exchange, an orange-, lemon- and grapefruit-marketing cooperative of 14,500 California and Arizona growers, produce tremendous quantities of citrus products which find uses not only in foods but in fields as diverse as medicine and the oil and rubber industries.

GLENN H. JOSEPH

California Fruit Growers Exchange, Corona, California

Introduction

THE citrus-products industry—a costly infant in the early 20's—has grown during the past quarter century to one of the world's outstanding examples of successful commercial utilization of an agricultural surplus. Wisdom in planning with confidence, foresight and patience in research and development, converted a botanical wastage to a national industry doing an annual business of more than $125,000,000. Students of economic botany may well pause to review this example of chemurgy as an illustration of the possibilities in their respective phases of this field.

One of the factors which stimulated products development in the citrus industry was the tremendous increase in fresh fruit production during the past two decades. The total citrus production in the United States, in terms of standard packed boxes of fruit, was:

56,000,000 boxes in 1926
93,000,000 boxes in 1936
196,000,000 boxes in 1946

This figure for the 1946 production may be visualized more easily by realizing that 196,000,000 boxes of fruit, stacked end on end, would extend upward 81,000 miles, one-third the distance to the moon! Although continual and extensive advertising campaigns have steadily increased the consumption of the fresh fruit, it has been necessary to utilize an increasing volume of fruit for products in order to give the industry a semblance of stability.

The manufacturing technic by which products of commercial value are prepared from citrus fruit, and in fact the variety of products made, differ widely among the several products factories in the different citrus areas of the United States. The present discussion, however, reflects more or less the citrus-products industry affiliated with the California Fruit Growers Exchange, an orange-, lemon- and grapefruit-marketing cooperative of 14,500 California and Arizona growers. The variety and inter-relation of products which are now manufactured by the factories affiliated with this Sunkist organization are shown in Fig. 1. Fig. 2 illustrates the location in the fruit of several important constituents and also points out the areas designated by the terms "flavedo" and "albedo".

Although citrus fruits include oranges, lemons, grapefruit, the mandarin or tangerine, lime, citron, kumquat and many other varieties, only the first three of this list will be included in the present dis-

cussion, because they are the only ones now of commercial significance in the California citrus-products industry.

Juice Products

Utilization of citrus juices for food purposes has not been a recent development. History reveals that more than 40 centuries ago "oranges and pummeloes" were presented as delicate gifts to a Chinese emperor. Records show that citrus fruits were known to the Pharaohs of Egypt in the 15th century B.C. During the centuries since that time many historical entries show the growing realization that the juices of citrus fruits possess healthful and even medicinal properties. The present generation, however, has been the first to attempt the preservation of citrus juices on a commercial scale.

Fig. 1 shows that juices are obtained by two general methods, crushing or pressing of the whole fruit and burring or pressing the juice from cut halves of the fruit. The juices produced by these two methods differ mainly in regard to the peel constituents which they contain. When whole fruit is crushed the juice usually contains a large portion of the essential oil from the outer rind or flavedo, and of course other peel constituents which are not removed when the juice is subjected to high speed centrifugal treatment for recovering most of the essential oil. These peel materials are responsible for certain flavor differences in the various types of juice. When juice is to be canned or frozen, at natural strength, the fruit is usually burred or pressed so as to avoid the peel materials and possible oil flavors which

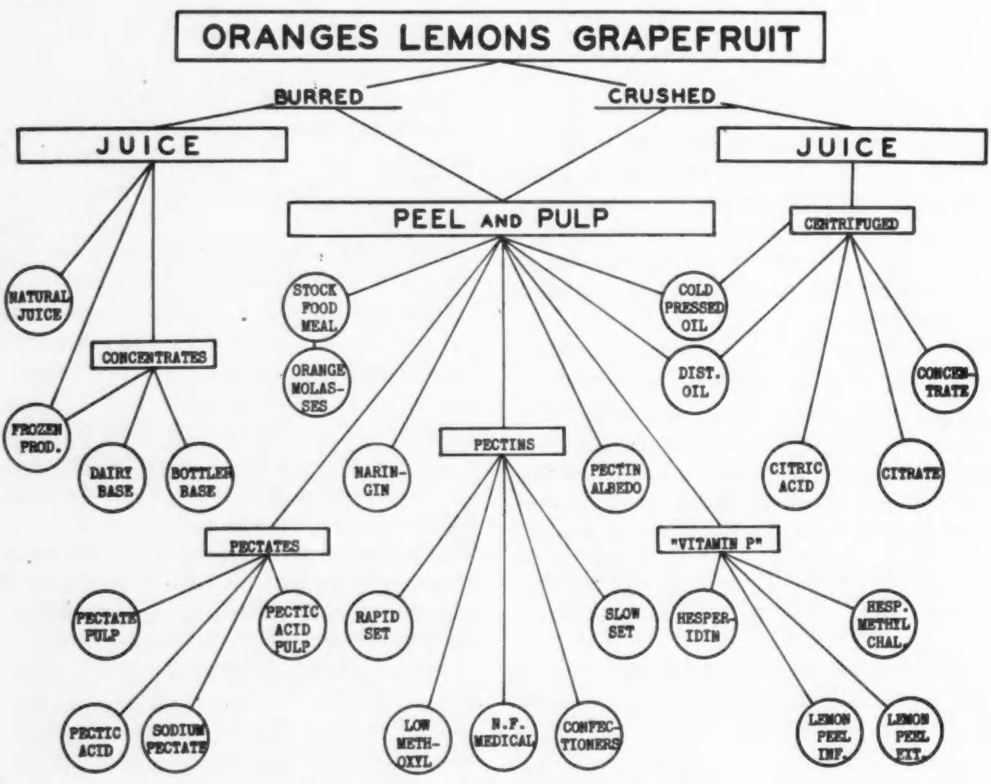


Fig. 1. Chart of citrus fruit products.

they may impart. Although much juice is still prepared by hand-burring or reaming of cut fruit, there are several mechanical methods available for preparing excellent burred juice.

Citrus juices contain pectic enzymes which act upon the small amount of pectin usually present and cause it to flocculate and carry down the fine suspended solids characteristic of freshly prepared juice. This self-clarification and subsequent sediment formation in packaged juices may be avoided by using a patented process of "flash pasteurization" developed in the Exchange laboratories. This process also permits maximum flavor retention.

A considerable percentage of the various citrus juices goes into concentrated and blended products designed to meet the varied requirements of the beverage industry. Concentration of the juices is usually accomplished by utilizing stainless steel vacuum pans where water removal is possible without appreciable temperature rise. The essential oils, sometimes desirable for maintaining the true flavor of the particular fruit and which may have been removed by the concentration process, are usually added after concentration or are supplied in an extract or emulsion form with the concentrated juice, to be added when the juice is mixed with sugar sirup prior to final bottling as a beverage.

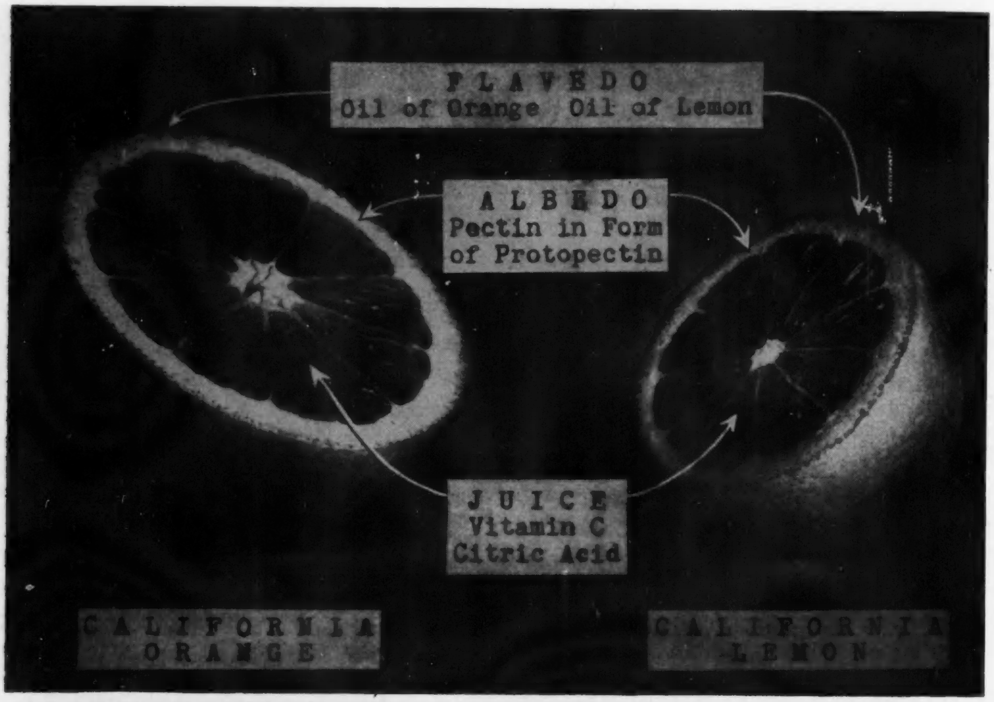
The juice from crushed fruit is usually passed through high speed centrifugal separators in order to remove the essential oil introduced from the peel. The resultant juices are frequently vacuum concentrated for use in certain blends where their flavor is desirable.

The successful production of citrus juices for world wide distribution has been made possible by years of careful research and is continuing only through diligent efforts by specialized bacteriologists, chemists, engineers and a wide range of other technical personnel. There are many, many physical and chemical factors which are involved with the extraction and preservation of such delicately flavored juices as those from citrus fruit. Research on the subject of citrus juices is today concerned not only with processing technics but goes back to cultural practices, picking and handling methods, and even to transportation factors. Investments in research and development have indeed been extensive.

These efforts have made possible the development of this phase of the products industry to the point that the production of canned natural strength citrus juices in the United States has reached an annual volume in excess of 60,000,000 cases (24 No. 2 cans per case). The annual volume of concentrated citrus juices in this country is usually about 1,000,000 gallons, although during the recent war period this figure was in excess of 3,500,000 gallons, due mainly to lend-lease purchases for fortifying the diets of children and expectant mothers.

Essential Oils of Citrus

The outer layer of the rind, or the flavedo, of citrus fruits contains the essential oils which are so widely used in the food industries as flavors. Fig. 1 shows that two types of oil are listed, cold pressed and distilled. The cold pressed type is the more important and is the only one admitted by the United States Pharmacopoeia. This type, from oranges, is listed in the U. S. P. XII under the heading "Oleum Aurantii", where the description is: "Oil of Orange is the volatile oil obtained by expression from the fresh peel of the ripe fruit of *Citrus Aurantium* Linné var. *sinensis* Linné (Fam. Rutaceae)". The corresponding oil from lemons is described in the U. S. P. XII, under "Oleum Limonis", as "Oil of Lemon is the volatile oil obtained by expression, without the aid of heat, from the fresh peel of the fruit of *Citrus Medica* Linné var.



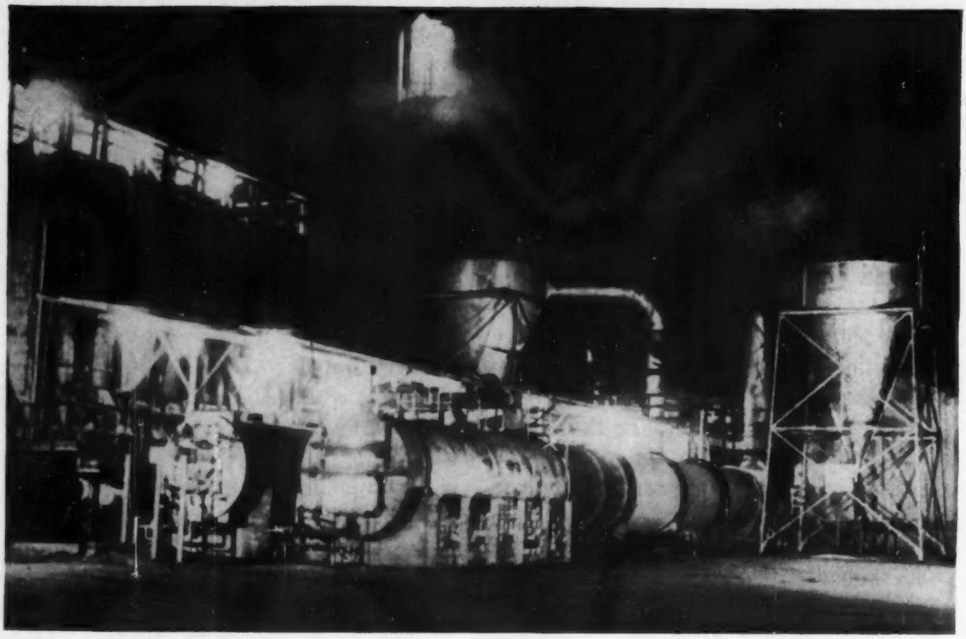


FIG. 2. (*Upper*) The parts of an orange and a lemon from which citrus products are obtained. FIG. 3. (*Lower*) One of the pulp drying units in Exchange Factories. (*Courtesy California Fruit Growers Exchange.*)

Limon Linné (Fam. Rutaceae), with or without the previous separation of the pulp and the peel". No corresponding definition for grapefruit oil has yet been made official.

The cold pressed oils, although actually existing in the peel, are usually obtained commercially from the juice into which they have been introduced during pressing of the whole fruit. The juices are passed through supercentrifuges in order to throw out the oil. There are certain mechanical means of expressing the juice of oranges and at the same time collecting the expressed oil during the same operation, without the aid of a centrifuge. It is for these reasons that cold pressed oils are shown in Fig. 1 as arising from both the juice and from the peel.

This same reason applies to the position occupied by distilled oils in the chart. The pressing and centrifuging methods are not quantitative in their removal of oil, and consequently some further amounts of oil may be obtained by steam distillation of the pressed fruit. The oils prepared by such a method are quite different in character from those made by cold pressing. Although the distilled oils may be used as flavor in certain food products, perhaps the greatest application of these oils is in the field of perfumes, as in soap manufacture.

The processes by which the cold pressed oils are handled so as to give them great clarity and stability are too complex to be treated here. The U. S. P. standards for these oils are quite rigid and require the utmost care in manufacture and considerable analytical work in laboratories to insure compliance with them. These oils are used in the food industries wherever the flavor of the particular citrus fruit is desired. The confectionery and baking industries are users of large volumes of orange and lemon oil. Household flavoring extracts, of course, also utilize these oils.

Citric Acid

The chart of products previously referred to shows citric acid and citrates as being derived from the juices of three varieties of fruit. Although it is true that citric acid is the main acidic material in the juices of fruits from all varieties of citrus, the amounts present in varieties other than the lemon and lime are too small to justify extraction with the present commercial methods. The juice of the lemon contains 5%–7% citric acid, about five times as much as is present in orange juice.

The methods in use today for preparing citric acid from lemon juice follow the same chemical pattern first used by Scheele more than 150 years ago. The juice after being subjected to about a week of spontaneous fermentation which permits easier and better later filtration, is heated to the boiling temperature and filtered sparkling clear. Sufficient calcium hydroxide suspension is added to the boiling hot juice to precipitate the citric acid as the salt, calcium citrate. The calcium citrate is later suspended in water and decomposed by the proper addition of sulfuric acid to give the insoluble calcium sulfate in a solution of citric acid. Ordinary filtration removes the calcium sulfate, and then citric acid may be crystallized from the filtrate and purified by any of several commercial processes.

Chemical control is necessary over all the steps in citric acid manufacture. The U. S. P. specifies that the product contain not less than 99.7% of pure citric acid in monohydrate form, and, further, limits the heavy metal impurities to not more than five parts per million. The principal salt of this acid is sodium citrate. Millions of pounds of the white crystalline acid and its various salts are used annually in this country in the food and pharmaceutical industries.

Pectin

Pectin is defined by the National Formulary, Eighth Edition (1946), page 374, as follows: "Pectin is a purified carbohydrate product obtained from the dilute acid extract of the inner portion of the rind of citrus fruits or from apple pomace. It consists chiefly of partially methoxylated polygalacturonic acids".

Pectic substances, although available since the creation of plant life on this planet, have been an article of human diet only since Adam and Eve began eating apples. Actual scientific publications describing the pectic substances did not appear, however, until the beginning of the 19th century. Pharmaceutical and medical applications of pectin were first mentioned in the literature in 1825. During the time since 1825 the scientific literature on the pectic substances has grown to voluminous dimensions, and the substances themselves have found many commercial uses, not only in foods and pharmaceuticals, but in industries as diverse as steel, rubber, paper and oil.

Botanists and plant physiologists commonly refer to pectin as the intercellular cementing material in the middle lamella and primary cell walls. Some investigators believe that pectin or its precursors coat the macro-mols of cellulose fibers. Recent physico-chemical studies indicate that the cellulose fibers are held together by intramolecular forces and that pectin and protopectin (the immediate precursor of pectin) form a chain-like network of intercellular material meshing in with the cellulose structure.

The pectic materials develop under conditions of rapid growth and high water content, and consequently they are present in large concentrations in fruits and stalks of fast growing plants and in the spring wood of trees. During ripening of fruits the pectin content steadily increases and reaches a maximum at maturity, then hydrolysis takes place. Enzymic hydrolysis converts the water-insoluble protopectin to the water-soluble pectin, and then on to the hydrolyzed and depolymerized pectates, and no doubt eventually to sugars. At all times the sum of the protopectin, pectin and pectates is probably a constant. At no one time, however, in this progressive change is there any considerable amount of water-soluble pectin. Pectin is responsible for turgidity of the cellular structure. After maturity, when enzymic hydrolysis has occurred, the structure weakens and complete dissolution of the framework takes place.

Although pectin is widely distributed in the plant kingdom, there are only a few sources at present capable of commercial utilization. These are in citrus peel and in apple pomace. Fig. 2 shows the location of protopectin and pectin in citrus fruits—in the white inner rind or albedo. The albedo contains about one-half of its weight in pectin, on the dried basis, although extracting processes capable of producing pectin with a high gel-forming ability fail to obtain a yield of any such magnitude. Since most uses for pectin are dependent upon its ability to give viscous sols and gels under certain conditions, and since these properties are enhanced by the highly polymerized state of the pectin molecular aggregate, the extraction process must be gentle. The pectic raw material is usually treated with a warm dilute acid to convert the protopectin to pectin, and then filtration separates the pectin solution from the cellulosic material of the fruit source.

Pectin may be precipitated from its water solutions by addition of an alcohol or by use of a polyvalent metallic ion, such as is furnished by aluminum sulfate or chloride. Both these processes are in use today for the preparation of citrus pectin. The final pectin product

made by either process is a nearly white powder with a mucilagenous taste and no odor. The production of dry pectin in the Exchange factories amounts to many thousands of pounds each month, and additional factory facilities for making pectin are under construction.

The chart of products lists the five most commonly known types of pectin made in the Exchange factories. These types may be made from either of the citrus varieties listed.

The most important pectins in the food field are the two types known as rapid and slow set varieties, used in jam and jelly-making. This designation refers to the time required, after all the ingredients have been added in the correct proportion, for a jelly to "set" or begin to show evidence of gel formation. Makers of berry jams prefer to have their product "set" soon after filling into containers, while still at temperatures above the sterilization point, so that the berries do not float to the top and leave a layer of clear jelly in the lower part of the container. This requires a "rapid set" pectin or what is sometimes designated as a "jam pectin".

Commercial jelly makers usually arrange to have their products remain fluid until the containers are filled, washed, labeled, packed into cartons and stacked. This requirement can be met by using a "slow set" or jelly pectin. Manipulation of the pectin molecular shape and size during manufacture is the means by which the setting characteristics of the pectins are altered.

Confectioners pectin became an article of commerce about 15 years ago, and with it came a "gum drop" of new and superior qualities. Up to that time various jelly and gum pieces had been made by using gelatin, starch, gum arabic or agar-agar and by combinations of these materials. Candies made from these materials had only a short shelf-life and were far from ideal in regard to flavor, texture and ease of manufacture.

A special type of citrus pectin was developed for use in confectionery where jelly pieces of excellent texture, flavor and stability were desired. This pectin

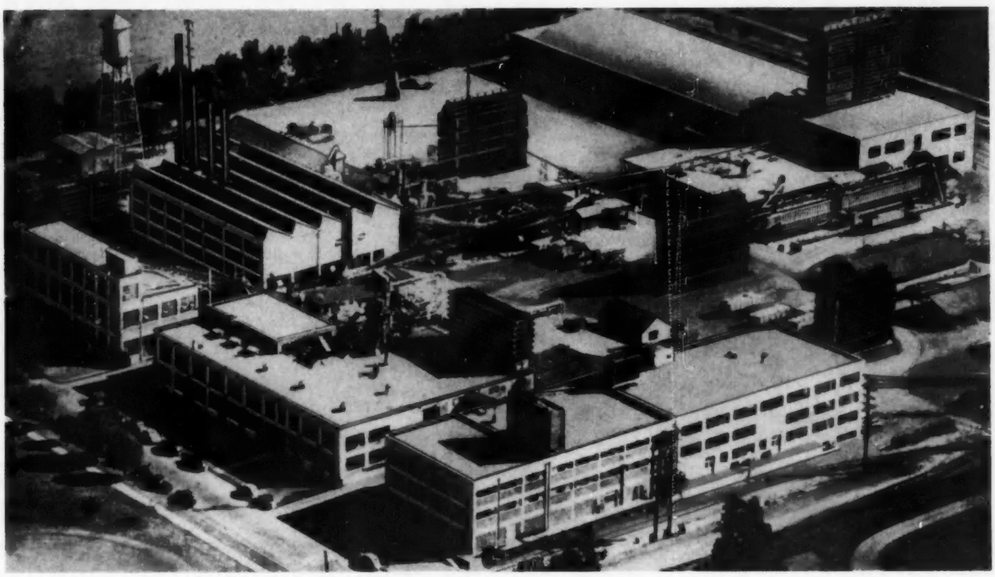


FIG. 4. The Exchange Orange Products Co., Ontario, Cal.

was quite slow setting so that even when the batches were cooked to a sugar content of 75%–80% and were properly acidified, the finished batch could be transferred by pipelines in the factory to automatic depositing or molding machines without danger of pre-setting. Many millions of pounds of "gum drops" and high quality jelly centers are made today from this special type of pectin which resulted from several years of chemical research and development.

Low methoxyl pectins are just beginning to enter the field of commercially valuable citrus products. The jelly, jam and confectionery pectins just mentioned, contain about 9%–11% of methoxyl groups, $-OCH_3$. All these pectins require more than 60% sugar for suitable final gelation. They are high methoxyl pectins, or strictly speaking, high-ester pectinates. During the past six or eight years it has been found that by removing some of the methyl ester groups from pectin there could be obtained a product which would form a gel even if the sugar were omitted, provided, however, that sufficient calcium or other similar metal were present.

These low methoxyl pectins are suitable for use in salads and desserts where sugar solids may be less than is required for the usual pectin gels. The gels formed by these new pectins result from a structure of pectinate molecular aggregates tied together by divalent ions such as calcium, and are not dependent upon any certain sugar content. Removal of the ester groups from pectins may be accomplished by using enzymes or a carefully controlled acid or alkaline treatment, or by combinations of these methods. The low methoxyl pectins are finding applications in the production of fruit salads and puddings, fruit mixes for ice cream making, fountain sirups, gels for diabetics, milk puddings, and in frozen berries and tree fruits.

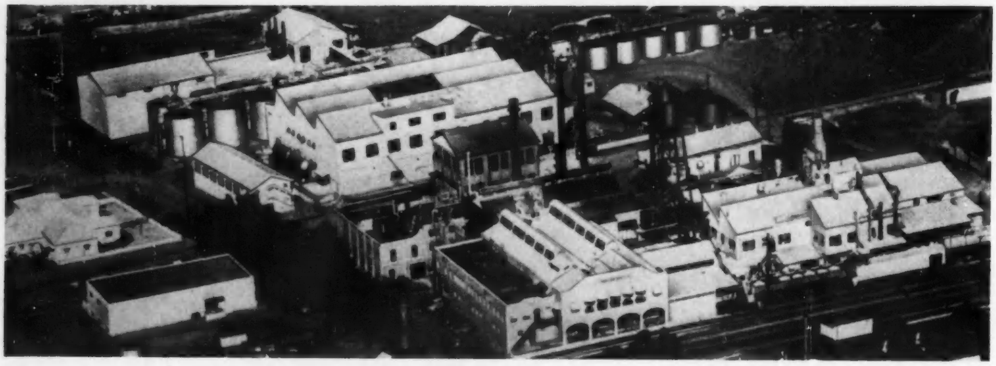


FIG. 5. The Exchange Lemon Products Co., Corona, Cal.

Medical uses for pectin were first mentioned by Braconnot in 1825, but it was not until 100 years later that pectin actually received attention in the medical journals. The use of pectin in the treatment of colitis, diarrhea and bacillary dysenteries grew out of the use of the apple diet which developed in Europe during the years following 1928 when the Heisler-Moro diet first became popular. Medical investigators in various countries soon concluded that the beneficial properties of the apple diet were due to the pectin of the apples. Soon the extracted pectin was used instead of the whole apple. At the present time many pharmaceutical products used for these intestinal diseases contain a purified pectin made to conform to the rigid standards of the National Formulary.

Hemostatic effects of pectin solutions were first reported in medical journals in France in 1924. Since that time

many hundreds of cases have been reported in the literature, cases in which pectin had been introduced intramuscularly or intravenously and produced a distinct accelerating effect on the coagulation of drawn blood. When pectin solutions in similar amounts are added outside the body to previously drawn blood, there is apparently no particular coagulating effect, and when pectin is added parenterally there is no coagulating effect upon the circulating blood.

During the recent world war much success attended clinical uses of properly prepared pectin sols for the transfusion treatment of shock, using the pectin sols as substitutes for human plasma. This particular application for pectin has not yet reached widespread recognition because human blood and plasma became so plentiful through volunteer donations that the emergency substitute was not needed. Extensive biological and clinical studies did show, however, that no undesirable effects resulted from the intravenous use of properly prepared pectin sols when used even in quantities substantially above the normally required dosage.

These intravenous uses for pectin made it necessary to maintain strict control of pectin quality and to produce as nearly a pure pectin as chemical research indicated was possible. The National Formulary (Seventh Edition and the new Eighth Edition) contains a monograph on and the specifications for such a product under the designation of Pectin N. F. The present medical uses for this high quality pectin, in addition to those already mentioned, extend to the preparation of pastes or salves, emulsions, tablets, powders and suspensions, for external and oral administration.

The Pectates and Stock Food Meal

The two materials classed as pectates in Fig. 1, which are the peel products of most interest from the viewpoint of the large scale utilization of surplus citrus fruit, are the "Pectate Pulp" and "Pectic Acid Pulp". These products, contrasted with those listed under pectins, are not highly refined and are sold by the ton rather than by the pound.

Citrus pulp includes the peel, after the oil has been removed from the flavedo, and the cellulosic structure remaining after the juice has been pressed or burred from the edible portion of the fruit. Disposal of a thousand or so tons of this material each day becomes a problem of major importance to factories attempting to recover salable products of citrus at reasonable cost figures. Early attempts at drying the pulp, which is not needed for pectin production, using ordinary large-scale drying equipment, met with failure.

Continued chemical research, however, developed pulp-treating processes which permitted the successful and economical drying of pulp in huge rotary driers, as illustrated in Fig. 3. The pulp so dried is being used as a stock food, especially in mixed feeds. Part of the liquors which result from the treating steps in making orange meal are further treated to produce a molasses-like material which is sold for use in connection with alcoholic fermentation processes and for certain stock food mixtures.

Pectate pulp and pectic acid pulp are additional products which are made in the same drying equipment as used for the stock feeds. When the citrus pulp is treated with an alkali the pectin is converted to a pectate and the natural calcium of the pulp reacts with the soluble pectate to produce water-insoluble calcium pectate in the cellulose matrix of the pulp. This dried pectate pulp, in a coarsely ground form, becomes dispersible in hot water when suitable amounts of added soda ash and a phosphate are present. These dispersions have been used for certain types of steel quenching, for aiding latex

creaming at rubber plantations, as an ingredient in oil-well drilling muds, for paper sizing, and as an antistick on paper containers for asphalt.

The pectic acid pulp is useful for the same general applications and differs from pectate pulp only in that dispersions may be made easily by merely adding any soluble alkali such as soda ash or ammonia. Slight alterations in the manufacturing processes permit production of these pulps with either high or low viscosity.

Pectic acid is a refined material separated from the pulp. It is insoluble in water but reacts readily with alkalis to give pectates. It is used as an acidulant in certain pharmaceutical powder mixtures, especially in effervescent mixtures where moisture absorption on storage in humid climates previously caused premature reaction between the ingredients and loss of effervescent ability. The only salt of pectic acid now of much importance is sodium pectate.

"Pectin-Albedo"

This term, originally coined to be descriptive of the product made by a specially perfected process, has grown to be recognized in the pharmaceutical and medical fields. The discussion above, under the heading "The Pectins," told how, in the peel of fruit, the water-insoluble protopectin is converted by natural enzymic processes to the soluble pectin and ultimately to depolymerized end-products. The patented process by which "pectin-albedo" is made consists of treating disintegrated peel with a mineral acid in alcoholic solution so as to hydrolyze the protopectin to soluble pectin but, due to the alcohol, keeping the pectin in its original cellulosic environment. This acid-alcohol treatment also removes colors and other soluble components of the peel, so that finally when the peel is alcohol-washed to free it of the acid and is later vacuum dried, there remains only relatively pure cellulose and easily water-soluble pectin.

"Pectin-albedo" is usually further treated by special rolling equipment to produce extremely thin flakes in which the cellulose units are all disrupted and the product can be added to water and taken orally for the treatment of certain intestinal diseases.

Flavanone Glycosides

Fig. 1 lists "Naringin" in one place and then shows four other materials grouped under the heading of "Vitamin P". This was done mainly because of the current interest in the so-called "Vitamin P" substances and because most investigators at the present time do not believe naringin has "Vitamin P" characteristics, even though it is a citrus flavanone glycoside.

The flavanone glycosides of citrus belong to the important and widely distributed group of plant pigments known as the flavones and are somewhat similar in chemical structure to the anthocyanins which are responsible for most of the blue, purple, violet and red shades in plants.

Studies on scurvy more than a century ago demonstrated that lemon juice corrected all the symptoms associated with the disease, including the capillary hemorrhages. Investigations during later years indicated that the vitamin C of lemon juice is the curative factor. When synthetic vitamin C became available, however, it was found to be ineffective in alleviating all the scorbutic symptoms related to capillary weakness. This led Szent-Györgyi and his associates to seek for a substance in lemon which had an activity and importance similar to vitamin C. The flavanone glycosides of lemon were isolated as a result and were termed "Vitamin P" (for permeability factor) in 1936 by Szent-Györgyi.

Therapeutic effects have been achieved

with the "Vitamin P" materials in a wide variety of cases associated with vascular permeability (or capillary fragility) such as:

- Vascular Purpura
- Psoriasis
- Increased Capillary Fragility in Hypertension

Hemorrhagic

- Telangiectasia
- Retinitis
- Measles
- Nephritis
- Capillary Toxicosis (particularly due to anti-syphilitic therapy)

Many flavanol and flavanone glycosides from a variety of plant sources have been discussed in the literature in connection with their relation to Szent-Györgyi's "Vitamin P" and their use in treating pathological conditions connected with capillary fragility and permeability. Some of these substances are: hesperidin; eriodictyol; quercitrin; rutin; epicatechin; hesperidin, methylated chalcone; and lemon peel infusion, dried.

Hesperidin is the oldest commercially available "Vitamin P" material. It may be prepared from either orange or lemon and is a grayish-yellow, non-hygroscopic powder, relatively insoluble in water and easily made into tablets.

"Hesperidin, Methylated Chalcone" is the name applied to the product obtained by methylation of hesperidin in alkaline solution where the pyrone ring structure opens and the material becomes soluble. It is a yellow, water-soluble powder which is proving to be a valuable member of the so-called "Vitamin P" group.

An aqueous extract of lemon peel, prepared so as to eliminate the pectins and the oils, then vacuum concentrated and dried, is being used under the name of "Lemon Peel Infusion, Dried". When lemon peel is extracted with alcohol and the extract is dried to a pilular mass the material is designated as "Lemon Peel Extract, Dried". It contains the same therapeutic principles as the infusion, and in addition has certain more desirable physical properties.

Naringin is a flavanone glycoside extracted from grapefruit peel and is used commercially for its extremely bitter taste. It has no known therapeutic properties. It has been used in Europe for imparting a desirable bitterness in beverages and in marmalade made from sweet oranges. One of the old household remedies for the common cold was to drink an infusion of grapefruit peel. No doubt the bitterness of the concoction imparted the belief that quinine was present, and perhaps some beneficial results may have been obtained from the vitamins known to be in citrus peel and from the increased fluid intake.

Concluding Remarks

This listing and brief description of citrus products has been presented to bring out the extent to which a group of agricultural producers has gone in order to preserve itself in this generation of economic perplexities. The difficult raw-material problems which beset the factories making the dozens of different products listed above can not be visualized by operators of the ordinary food and chemical factories. The fruit used as a raw-material differs continually, not only in degrees of maturity and in seasonal and varietal respects, but also as a result of locality and soil variations. Another difficult manufacturing problem arises from the fact that the quantity of fruit available for converting into products varies suddenly and from reasons which can not always be foreseen. It is not a matter of knowing what can be sold as products and then obtaining the needed raw-material; it is rather an obligation to take *all* the fruit available from the packing houses when and if they desire to have it converted to products.

Dozens of trained chemists, bacteriolo-

gists and engineers, working not only in expensive and well equipped laboratories, but in key positions throughout management and the factories, are essential to the products manufacturing operations, such as are being successfully conducted by the California and Arizona citrus growers.

Utilization Abstracts

Tropical Plants as Sources of Pectin. Nearly all commercial pectin is obtained today "as a byproduct of the citrus juice and apple cider industries. In the former, pectin is extracted from the peel of the citrus fruit and in the latter it is recovered from the apple pomace, the residue of the cider presses". Industrially pectin is used as a jellying agent in fruit juices and pulps to produce jellies and jams, "as an inert carrying agent for many pharmaceutical preparations, as a sizing agent in the textile industry, as a protective agent in the baking industry, as a creaming agent in the rubber industry, and as an emulsifying agent for many products".

In an effort to find other sources of pectin the Hawaii Agricultural Experiment Station has investigated a number of tropical and subtropical fruits, and has found that common guava (*Psidium Guajava*), papaya (*Carica papaya*), soursop (*Annona muricata*), tamarind (*Tamarindus indica*) and pomelo (*Citrus maxima*) have high pectin content, ranging from .80% to 2.07% of fresh weight, but not enough for commercial development.

The 12- to 18-inch long pods of pink shower (*Cassia grandis*), after removal of the beans, were found to have 16.5% pectin, an amount comparable to some of the established sources of pectin. The beans contain a water-soluble gum that may have value as a creaming agent for rubber or in other capacities.

In addition to the fruit of the common guava and the pod of the pink shower as potential sources of industrial pectin, there is also the pulp residue produced in the root starch industry. Large quantities of root starch are used each year as a sizing agent in the textile industry. The starch is mechanically separated by very fine mesh screens from the finely ground roots, and the residual material is subject to extraction. (*G. D. Sherman & Y. Kanshiro, Chemurgic Digest 6(4): 65. 1947*).

Furfural. Furfural is a technologically important substance "produced commercially in large volume by the action of sulfuric acid on oat hulls, but the use of corncobs, cornstalks, cotton stalks, peanut hulls, beet pulp, wheat husks and other waste agricultural products has been investigated. Any substance containing pentosans is a potential source of furfural.

"The discovery of furfural in 1832 was quite by accident, and until the institution of its commercial production in 1921, it remained a laboratory curiosity. Today, as a result of widespread developmental investigation, it is used on a large scale in such diverse applications as petroleum refining, the purification of butadiene for synthetic rubber production, the improvement of wood rosin, the preparation of plastics and resinous bonding materials, and in organic synthesis for the preparation of pharmaceuticals, insecticides, dyes and other products". (*F. L. Austin, Chemurgic Digest 6(9): 145. 1947*).

Lonchocarpus—*A Fish-Poison Insecticide*[1]

The roots of this tropical vine are the source of the valuable insecticide rotenone, non-toxic to humans, and were imported into the United States in 1946 from Brazil and Peru, from both wild and cultivated material, to the extent of more than 11 million pounds.

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Introduction

MANY an observant Amazon traveler has enthusiastically related how Indians of that region stupify fish by polluting small pools and sloughs with toxic plant infusions, including those prepared with roots of certain *Lonchocarpus* species. One of the most charming of these accounts was prepared for the Smithsonian Institution Report of 1930 by the tropical plant explorers Killip and Smith. It details not only the technique of staging a "pesca", or fish-poisoning expedition, but it also conveys the festive spirit with which the drama is enacted by those people who have the primitive's genius for mitigating work by playful diversion. Fish catching with the aid of lonchocarpus roots is an ancient practice, perhaps rivaling in antiquity the comparable use of *Derris* root in Malaya. As intriguing as the fact that primitive men of both tropical America and Asia discovered identical uses for these legumes is the close botanical relationship of the plants themselves. Their remarkable similarity suggests evolution from a common origin, although their native habitats, as we now know them, are separated by half a world of sea and portions of continents.

History

The identity of the pioneers who discovered the insecticidal value of lonchocarpus and derris is as obscure as that of those who found them toxic to fish. One can only speculate on how long derris had been used by Malayan gardeners as an insecticide before 1848 when Oxley wrote in the Journal of the East Indian Archipelago that it was effective against leaf pests on nutmeg trees. Likewise it is anybody's guess how long South American Indians were using lonchocarpus before 1910 when Gerardo Klinge delayed his travels in the Peruvian Valley of Huancayo long enough to verify that it would kill the sheep tick.

In 1902 the Japanese chemist Nagai isolated colorless crystals primarily responsible for the toxicity of derris root. This pure substance, which he named "rotenone", was found subsequently in 1926 to be the principal active ingredient in the root of lonchocarpus as well. Thus the similarity between these two tropical legumes appeared even more striking. As the definite practical value of rotenone-bearing roots became established by laboratory tests of entomologists, insecticide manufacturers in

[1] Much of the material in this paper is taken from the writer's manuscript on Lonchocarpus, Derris and Pyrethrum, prepared for publication by the United States Department of Agriculture and the Pan American Union. This study was made possible by funds provided through the United States Interdepartmental Committee on Scientific and Cultural Cooperation.

Europe and the United States began importing roots from the Far East and the Amazon to compound commercial dusts and sprays. Impetus was added to the demand for these insecticides when it was determined that they are non-poisonous to man and other warm-blooded animals. They can be used effectively against certain pests of truck and canning crops without hazard to the human consumer. Dip solutions are harmless to livestock while lethal to ticks, warbles, lice and fleas. By 1932 the infant rotenone industry was assured a vigorous maturity. Its insecticidal products are now recognized as among the most effective agents for combating the Mexican bean beetle, wooly apple aphid, European corn borer, pea aphid, housefly, mosquito and cockroach. Associated with rotenone, but less toxic, are a number of other active substances collectively known as "rotenoids" which add to the effectiveness of derris and lonchocarpus.

The discovery of the insecticidal value of these two leguminous fish poisons was a challenging clue to botanists in many parts of the world. Libraries were searched for accounts of fish-poison plants; expeditions were organized to canvass fields and forests for all closely related species. Hundreds of specimens were collected from several continents for the scrutiny of entomologists with encouraging though unspectacular results. Numerous other Papilionaceae, including species of *Tephrosia*, *Pachyrhizus*, *Mundulea* and *Millettia*, have been found to contain rotenone and rotenoids but not in sufficient quantity to warrant commercial exploitation without modification by geneticists who may eventually breed strains of superior quality. To date, most progress has been made with *Tephrosia virginiana* by Russel, Little and their collaborators of the United States Department of Agriculture and of the Texas Agricultural and Mechanical College, but the years of exploration for rotenone-bearing plants which may equal or surpass the two now in commercial production are by no means concluded.

Prior to the recent war derris-growers in the Far East exceeded the rotenone-root production of Amazon river-bank-dwellers, since the latter hesitated to make large plantings of lonchocarpus so long as they could more easily exploit numerous small reserves originally established for fish poison purposes. Persuaded by root grinders in Belem, the Brazilian state of Pará in 1934 imposed an export embargo on crude root so as to channel all local harvests into the processors' hands. This action likewise restricted planters' enthusiasm in what was once the most important center of lonchocarpus production, since the millers, protected by their new law, held prices they paid to gatherers at a minimum, while export values of their powdered roots soared on an expanding world market.

The Japanese invasion of Far Eastern derris countries deprived the United States of approximately one-half its prewar supply of rotenone-bearing roots; so early in 1942 the incentive of attractive long-time minimum price guarantees was offered to South American lonchocarpus producers in hope they would swing into large scale operations. Peru responded as quickly as could be expected, since the crop requires two and one-half to three years to mature. In December, 1942, Pará revoked its export embargo on cultivated crude roots so that growers could obtain a share of the new incentive prices, but to this day Brazil has not recovered its once preeminent position. In 1946 the United States, which is the world's largest rotenone consumer, imported a record 11,369,322 pounds of crude and powdered roots. Of this amount only 29,764 pounds were derris and the re-

UNITED STATES IMPORTS OF ROTENONE-BEARING ROOTS, CRUDE AND POWDERED, IN 1,000-POUND UNITS

Country of Origin	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946
Lonchocarpus										
Brazil	1,562	1,793	1,101	1,047	1,311	193	1,469	554	94	473
Peru	378	477	1,730	2,225	2,525	2,503	2,079	5,452	8,604	10,862
Other (Western Hemisphere)	......	55	170	74	61	......	22	321	71	5
Total	1,940	2,325	3,001	3,346	3,897	2,696	3,570	6,327	8,769	11,340
Derris										
British Malaya	402	583	2,326	1,842	1,930	653	......	......	......	......
Neth. East Indies	57	136	280	997	1,700	430	......	......	......	......
Philippine Islands	111	23	262	231	377	19	......	......	2	......
Other (Western Hemisphere)	......	......	......	......	......	......	......	......	3	13
Other (East Asia and Africa)	2	2	40	152	93	......	......	......	45	16
Total	572	744	2,908	3,222	4,100	1,102	......	......	50	29

mainder lonchocarpus. Peru supplied over 95% of the total. Even these imports were not sufficient to satisfy a potential United States demand estimated at about 25 million pounds of 5% rotenone content from which approximately 125 million pounds of commercial insect powders or their equivalent could be manufactured.

ESTIMATED WORLD PRODUCTION OF ROTENONE-BEARING ROOTS (DERRIS AND LONCHOCARPUS) IN 1,000-POUND UNITS

Country	1938	1939	1940
Brazil	2,500	1,500	1,000
Peru	1,500	2,500	3,000
Venezuela	(1)	200	100
British Malaya	2,000	3,500	3,000
French Indochina	(1)	300	150
Japan	100	650	(2) 2,000
Netherlands East Indies	250	1,500	1,750
Philippine Islands	200	650	900

(1) Not available.

(2) Anticipated production as reported from that area.

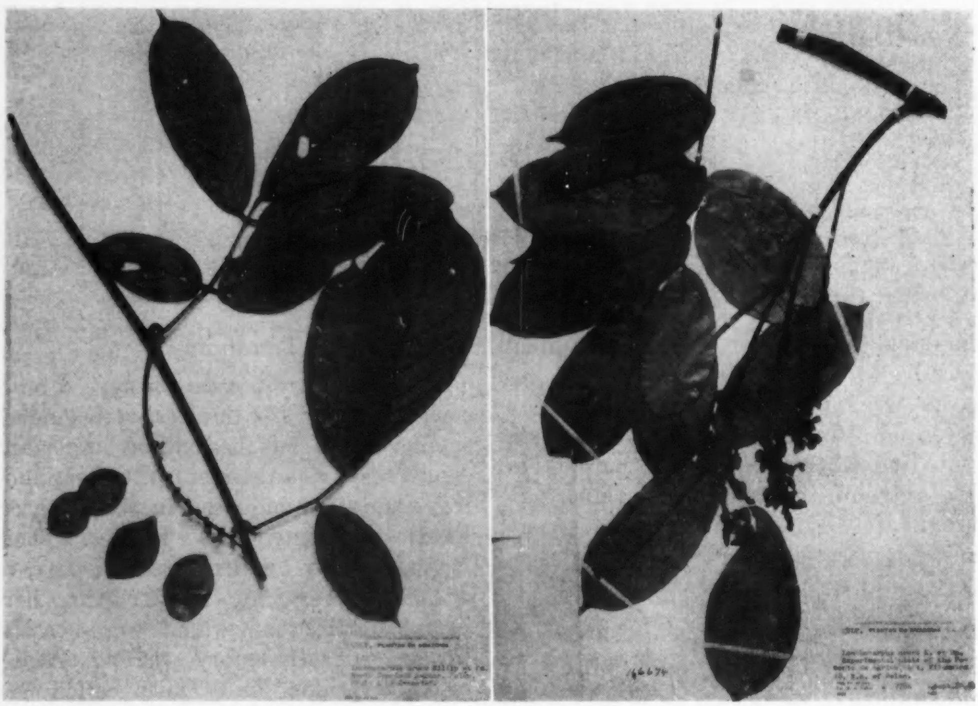
Taxonomy

Botanists have not as yet agreed on a scientific name for the Peruvian lonchocarpus which has become so important commercially as the result of an expanding plantation industry in the Amazon headwaters region above Iquitos. Their hesitancy may be attributed, in part, to a lack of flowering and fruiting herbarium collections which would assist toward a satisfactory taxonomic decision. Krukoff and Smith called this plant *L. utilis* after having studied their collections of leaf specimens. Additional field and herbarium research lead Hermann to name it *L. Nicou* var. *utilis*. In his Flora Of Peru, MacBride even classifies it as a form of *Derris*. From a horticultural as well as a commercial viewpoint it is helpful to maintain a generic distinction between the South American and the southeast Asian plants; so it is fortunate that most systematists continue to call it *Lonchocarpus,* even though they do not agree on a species name.

Rare flowering and even less frequent fruiting are apparently characteristic of the commercially important lonchocarpus species. In 1944 research workers at Tingo María, Peru, induced flowering by girdling branches of two-and-a-half-year-old plants; so, possibly, taxonomists may eventually secure fertile specimens to study. The type specimen of *L. nicou* was collected in French Guiana and was described by Aublet in 1775. Today only leaf fragments remain of that material, and there are apparently no known fertile collections of authentic French Guiana *L. nicou* available to taxonomists.

The only well documented species of commercial lonchocarpus is *L. urucu* which was named by Killip and Smith in 1930 after their explorations in the Brazilian Amazon where they gathered specimens with flowers and legumes. *L. urucu* is the source of most of the roots exported from Brazil. Perhaps until adequate fertile collections are obtained of French Guiana *L. nicou* and of the Peruvian species which Krukoff and Smith call *L. utilis*, the taxonomy of the most important insecticide plant produced in the Western Hemisphere will remain confused.

In its native habitats lonchocarpus is known by various common names, all of which connote its value as a fish poison in the local tongues. In Peru it is referred to in Quechua as "cube" and in Spanish as "barbasco". It is designated as "timbó" in Brazil, "haiari" in British Guiana and "nekoe" in Surinam.



FIGS. 1 & 2. Fruiting and flowering branches, respectively, of *Lonchocarpus urucu*.

Sources of Commercial Supplies

Although plants of the genus *Lonchocarpus* are rather widely distributed throughout the Western Hemisphere, the present commercial rotenone-bearing species are native only to certain trop-

ical rain-forest areas of South America. Previous to 1939 most of the total crude and pulverized root entering world markets was harvested in the Brazilian states of Amazonas and Pará. Since then, however, the quantity grown for export on Peruvian plantations has steadily increased to the current figure. At the present time, judging from the volume of production, approximately 12,000 to 18,000 acres are planted in eastern Peru. By comparison the cultivation of this crop for export has hardly begun in Bolivia, Ecuador, Colombia, Venezuela and the Guianas where rotenone-bearing species are also native. Only slightly more interest has developed in Brazil despite that country's one-time dominance of the market.

The principal production centers in Peru are located near the villages of Lagunas, Yurimaguas and Tingo María on the Huallaga River; Jeberos between the Huallaga and the Marañon Rivers; Contamana on the Ucayali River; Barranca and Nauta on the Marañon; Iquitos and Tamshiyacu on the Amazon; and Satipo on the Satipo which is a tributary of the Tambo river. In Brazil plantings are found near Belem, Portel, Mazagão and Macapá which are close to the mouth of the Amazon; at Porto de Moz on the Xingu; at Belterra on the Tapajoz; and in the environs of several villages along the Amazon, Negro and Madeira rivers in the State of Amazonas. In Venezuela small plantings are reported near El Tigre in the state of Anzoategui and on the Orinoco islands of Urbana and El Infierno on the western border of Bolivar State.

Since the value and technique of cultivating the plant is little known outside of Peru and a few villages in Brazil and Venezuela, many years may pass before lonchocarpus becomes established as a commercial crop in any other tropical country. If it is eventually determined, however, that it has a cultivation range approximating that of derris, it may replace derris to some extent, since, using present cultural methods, it requires less labor to produce equivalent amounts of rotenone.

Field Preparation

Present methods of lonchocarpus culture are those developed through trial and error by Amazon Indians and river-

FIG. 3. Planting lonchocarpus cuttings in eastern Peru.

bank settlers who sought to provide themselves with adequate supplies of fish poison.

Plantations, or barbascales, as they are known in Peru, are often established on what previously has been woodland, since in the rain-forest areas of the Amazon basin it is generally considered an easier and more profitable task to open up new clearings in the forests than to reclaim old cultivated fields from the

weeds and keep them clean. This practice prevails partly because draft animals, moldboard plows and mechanical cultivators are almost unknown, and because it is too difficult to combat the vigorous encroachment of grasses with simple hand tools, such as the hoe and the machete.

When a timbered area is felled and burned over, it may be littered with charred stumps and logs, but for several years the farmer finds comparatively little grass growth competing with his crop. Of course, animal- or tractor-drawn implements could not be used on land cleared in this superficial manner, even if the farmer could afford them.

Reduced soil fertility, due to the leaching of certain elements and rapid oxidation of organic matter, also contributes to the planter's decision to abandon lonchocarpus sites to volunteer forest after two or three crops have been grown and to open up new land by clearing woodland areas. Aside from this primitive forest-crop-forest cycle which may be repeated after long intervals and which provides a generous although poorly distributed top dressing of wood ash minerals to the soil, the Amazon axe and machete farmer has not yet developed field crop rotations and manurial treatments which will maintain the productivity of upland soils indefinitely. Some of the soils on which crops are grown under this system of shifting cultivation would not be capable of continuous clean cultivation, even with better treatment. They would rate as submarginal lands that would not have been




FIG. 4. (*Upper left*). Packing bales of lonchocarpus roots at the Victor Israel Co. warehouse in Iquitos, Peru.

FIG. 5 (*Upper right*). A log-strewn field in eastern Peru ready for planting cuttings.

FIG. 6 (*Lower left*). A plantation of three-year-old lonchocarpus.

FIG. 7. (*Lower right*). The exposed root system of a lonchocarpus plant.

cleared had permanent agricultural use been contemplated, but they are fully capable of producing one to several satisfactory crops before they must be abandoned to volunteer bush cover.

Land clearing operations generally take place during the drier months of the year, so that undergrowth and the leaves and branches of fallen trees will have an opportunity to dry out sufficiently to burn. In the Amazon region there is little danger that brush fires will spread beyond the clearings into the green growth of the surrounding rainforest; so on a clear day, when the trash is dry enough and there is relatively little wind, it is set ablaze. The flash burn consumes the mass of debris within a few minutes, but slow smouldering fires ignited in stumps and logs may continue for days or weeks. No further seed bed preparation is practiced by the grower who simply waits until the subsequent rainy season to plant his crops.

Propagating Material and Field Planting

Techniques used to cultivate lonchocarpus resemble those employed by the Amazon native to grow yuca, *Manihot esculenta* Crantz, which is his principal subsistence crop. Both plants are vigorous and will return fair yields, even though cultivated in a rather haphazard manner. For propagating material the planters use leafless stem cuttings 10 to 18 inches in length and from three-quarters to two inches in diameter. The average farmer exercises little care in the preparation of these cuttings which are often needlessly bruised and crushed or even exposed to sun and rain before planting. As a consequence a mortality of 50% or more is not unusual. By observing reasonable precautions survival can be 80% or more. The cuttings which usually possess from three to six axial buds are set into holes made with digging sticks, hoes or machetes. They are inclined at angles varying from approximately 15° to 60°. The apical portions with one or two buds are left exposed, while the remainder of the cuttings are covered with soil which is firmed around them by the tramping of the planters' feet. One or two cuttings are placed in a single hole, and sometimes two or more holes may be dug side by side. Some planters even dig a series of holes to form such circles, squares, triangles and rectangles. Seldom is a field laid out in rows or check rows, since the tangle of stumps and fallen logs makes precise spacing impossible. Distances between plants and planting designs are not standard. Reports range from three to 12 feet, although five to seven feet seems to be most common. Closer spacing is generally practiced when only one or two cuttings are used at each location and where skips are likely to occur due to poor survival of the cuttings.

Interplanting

The average rural Amazonian is a subsistence farmer and hunter. He grows crops such as yuca, beans, corn, rice, bananas, plantains and okra to assure himself a minimum food reserve. He also gathers a portion of his sustenance from the forest and the rivers. Wild nuts, fruits, roots, palm hearts, fish and game contribute to his diet. He requires a small amount of money to buy tools, clothing, patent medicines, ammunition and other essentials. Lonchocarpus is a cash crop ideally suited to his needs. It requires two and a half to three years to reach maturity, and during the first year while the plants are still small they can be conveniently interplanted with food crops which will not interfere with development of the lonchocarpus. During the second and third years the lonchocarpus grows to a height of six to eight feet, and the plantation broadens into a bushy thicket. At that stage interplanting becomes impractical, although

mats of bananas, plantains and pineapples which have become established are left undisturbed. The average lonchocarpus planter has several small fields at various stages of maturity, and in those which have recently been established he has little difficulty finding room for his subsistence crops.

Weeding

Using hand tools, as is the present custom, the average family raising lonchocarpus cannot maintain more than five to six acres in production at any single time. Experienced growers at Lagunas, Peru, in 1943 informed the writer that a hectare, or 2.4 acres, of two-and-a-half to three-year-old plants on virgin land, which will normally yield about 10,000 pounds of green root or 5,000 pounds of air dry root, requires an average of 300 man days of labor. This figure was reduced to averages of 115 days for clearing and burning the virgin forest, 20 days for cutting up stems of mature plants for propagation material and planting them, 85 days for chopping weeds and 80 days for harvesting. On old cropland approximately 360 to 400 man days were required to produce such a crop. The initial effort to clear the land was less, but considerably more time was spent in chopping back weeds with a machete during the subsequent years. Once established a field requires no attention other than occasional weedings until harvest time. If the stand is a relatively full one, as the plants grow taller and broader they tend to shade out weed growth.

Harvest and Preparation for Market

The harvesting of lonchocarpus roots is a task requiring stamina. The fresh roots of two-and-a-half-year-old plants will ordinarily weigh from one to five pounds. As a general rule, most of the roots spread out laterally but a few grow almost directly downward. The gatherer's job is to salvage as much of the entire root system as possible. To accomplish his work he first severs the trunks of the plant about a foot and a half from the ground with a few machete slashes. He then pries under the crown of the plant with a long, stout, sharp-pointed pole which he drives into the ground with several vigorous jabs. By exerting some leverage on the end of the pole he is able to lift the crown slightly above the level of the soil so that he can see where the main roots are attached. He then severs the roots on one side of the plant and pulls them from the ground individually. If they are very large roots or penetrate more than a few inches below the surface of the ground he may be obliged to pry them loose with his stick or dig them out with his machete. The roots still attached to the crown are more easily removed by pulling backward on the attached butt of stem and ripping them out of the soil, sometimes with the assistance of the digging stick or machete. The operation takes a strong back and arms, and only a man of considerable endurance can engage in this task for more than five or six hours a day. The average farmer gathers and carries away from the field about 125 pounds of fresh roots in a day's time. To facilitate carrying he securely ties his roots into a single large bundle bound with long pieces of forest liana.

By harvest time the average independent grower has had to borrow cash advances on his crop from his patron or from a local merchant. In payment of these debts he may deliver his roots to his creditor. He may, on the other hand, sell his entire plantation at harvest time to a representative of some commercial company. These representatives, known in Peru as "regatones", will contact the individual grower and offer him a price. If the proposal is accepted the planters' debts are paid to his creditors by the *regaton*.

Patrons, merchant creditors and the commercial houses represented by the regatones maintain crudely built shelters in the principal production centers where they collect and store the fresh root until they have enough to ship by steamboat to the port of Iquitos. Some patrons and regatones who operate on a small scale may even transport their collections by dugout canoe or balsa raft. When the roots arrive in Iquitos, those which are not already owned by the larger export companies are bought and stored for air-drying in the exporters' warehouses. Roots which are exported crude are kept in storage several months until their moisture content has been reduced to approximately 20% of their weight. (When fresh they contain about 60% moisture.) Then they are packed into bundles wrapped in burlap or unbleached muslin. On the ocean voyage they usually lose considerable moisture and arrive in the United States in a fairly dry condition.

In recent years a grinding industry has been established in Iquitos, Peru. Roots for grinding are first air dried, then chopped and oven dried before being passed into the mill. The final product, all of which is 200 mesh or finer, is packed into bags for shipment.

Selection of Superior Quality Strains

The commercial value of lonchocarpus roots on the United States market is determined by their rotenone content, even though insecticide manufacturers and entomologists recognize the secondary importance of the rotenoids. Consequently the growers of both lonchocarpus and derris are particularly interested in cultivating those strains which will yield roots of highest possible rotenone percentage. As with many other economic plants, the first major task of selecting superior strains from nature's miscellaneous variety was probably accomplished by primitive man. Perhaps in their search for effective fish poisons the aboriginal inhabitants of the South American rain-forests discovered and propagated some of the more potent lonchocarpus plants. The majority of contemporary commercial barbascales have been established from lines of plants perpetuated by the Indians and more recent immigrant settlers.

When the commercial possibilities of lonchocarpus production were recognized in both Brazil and Peru in the early 1930's the most enterprising mercantile houses, operating through their rural intermediaries, established collections of living plants from the areas where they purchased the best grades of roots. In Peru a few of these introduction gardens eventually expanded into community plantations where individual families now grow a few acres each and where the total area dedicated to the crop in some cases involves 1,000 to 3,000 acres.

In 1942 the Instituto Agronomico do Norte at Belem, Brazil, began a systematic study of hundreds of mature individual lonchocarpus plants of both *L. urucu* Killip and Smith, and *L. utilis* Krukoff and Smith, which had been brought to Belem by plant explorers. Chemical analyses of samples taken from the roots of these individuals revealed a range in rotenone content from 0.9% to 20.1% among 148 plants of *L. utilis* which were estimated to be between three and five years of age. Weights of fresh roots harvested from these individuals varied between 20 and 3,895 grams. At the same time 232 individual *L. urucu* plants approximately three to five years of age were studied in the same way. Their rotenone content ranged from a low of 2.2% to a high of 11.2% and fresh root weights varied between 25 and 6,420 grams. At the present time the average commercial

root shipments contain from 4% to 6% rotenone.

An interesting feature of the Instituto Agronomico do Norte's work is the observation that certain high root weight producing *L. urucu* strains may be more profitable to cultivate than the commonly preferred *L. utilis* which usually produces a higher rotenone content but less root weight during an equal growth period. As the Instituto Agronomico do Norte technicians emphasize, the commercial producer should be interested in achieving the highest total of rotenone per acre per year.

Work similar to that being done in Belem is being conducted by the Estacion Experimental Agricola de Tingo María in Peru and by the Estacion Experimental Agricola del Ecuador at Pichilingue on the Vinces River in Ecuador.

Bananas. The following are the principal varieties of banana cultivated in the American tropics.

Gros Michel. This variety, known also as the Jamaica, Martinique and Roatan banana, is the variety that has attained the greatest commercial importance and is nearly the only one commonly known in the United States. The "fruit is never allowed to ripen on the plant, as the skin bursts open and the pulp falls prey to insects and birds. In addition, the pulp becomes granular in texture, and the flavor is less palatable. Bananas are always cut green but at varying stages of maturity depending upon the ultimate destination. If the shipment is for European consumption, greener fruit is cut than that intended for the United States and Canada".

"The usual marketable bunch or stem of Gros Michel has from 8 to 10 hands, or clusters, each containing approximately 18 fruits, called fingers, making from 150 to 180 bananas in all. . . . Of nearly 90,000,000 bunches of bananas exported annually before the war from Mexico, Central America, the West Indies and South America, at least 90 percent were Gros Michel. The United States took roughly, 55,000,000 of the total amount".

Claret. This variety with purplish-red skin is little known in the North, but sometimes appears in markets at Christmas time. The flavor is similar to that of the Gros Michel, but the texture is rather gummy, and the bunches are smaller with fewer hands and fingers.

Lady Finger. Known also as Golden Early, Rose or Date banana, this delicious variety is only three to four inches long and is popular in Latin America. Its thin and easily bruised skin hinders profitable shipment.

Apple. Thin-skinned and similarly difficult to transport, this variety, too, is not known in northern markets. It is four to five inches long and has an apple-like odor and a rather granular texture.

The foregoing are but four of the 150 to 200 known varieties of the species *Musa sapientum* L., nearly all of which are food producers.

Cavendish. This one, known also as Chinese, Canary and Dwarf banana, is the variety *Cavendishii* of *M. nana.* It ranks second in commercial importance after the varieties of *M. sapientum,* and produces bunches of 200 bananas sometimes as large as those of the Gros Michel. The plants are only five to seven feet tall, however, instead of up to 25 feet as are those of Gros Michel. This variety is more important in southeastern Asia, lands of the central Pacific Ocean, Africa and the Canary Islands than in the western hemisphere.

Plantain. Plantains, known in several varieties according to shape, size and color of the fruit, differ from the foregoing forms in having to be boiled, fried or baked before being edible. They are all forms of the species *Musa paradisiaca,* and some of them yield the largest fruits of the banana family. These cooking bananas have for long been a basic food of hundreds of thousands of people in tropical lands. (*D. E. Farringer, Agriculture in the Americas 7(4–5): 63. 1947*).

Some Promising Insecticidal Plants

In addition to tobacco, pyrethrum and the rotenone-bearing plants of the genera Derris and Lonchocarpus, seventeen of which are discussed in this paper, have been found promising as sources of insecticides.

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Introduction

NEARLY 1,200 species of plants have been reported in the literature to be of possible insecticidal value (29), but of these only a few—tobacco, pyrethrum and the rotenone-bearing plants *Derris* and *Lonchocarpus*—are used extensively. It is the purpose of this paper to call attention to some of the other plants that seem to have sufficient insecticidal properties to justify further research to ascertain their possibilities in insect control. Although the entomologist now has DDT, benzene hexachloride, chlordane, hexaethyl tetraphosphate and other synthetics with which to fight pests, he needs additional weapons in order to wage war against an increasing number of insect enemies. The synthetics are specific in their action on insects, proving to be highly toxic to some species and practically inert to others. No one insecticide answers all purposes. In the development of new insecticides, those derived from plants deserve careful consideration because they are highly effective against many of our worst insect enemies, are harmless to other plants and are relatively non-toxic to warm-blooded animals.

The plants mentioned in this review are those which appear to be especially promising for use as insecticides. However, so little research has been done with plant constituents as insecticides that many additional plants will doubtless be found useful in the control of pests. A search for new insecticides among plants will amply repay the investigator who takes care to avoid the numerous pitfalls in such an undertaking (36).

Plants contain not only toxic materials valuable as contact or stomach poisons to insects, but also substances useful as synergists (sesamin), wetting and emulsifying agents (saponins), adhesives (rosin oil) and stabilizers (tannin) to be used with pyrethrum, rotenone or other insecticides.

In the following discussion the plants are treated alphabetically, according to family and to genus. A more logical arrangement would be according to the chemical nature of the insecticidal constituents in the plants, but the limited information on the chemistry of these compounds does not permit this classification. Also, insufficient work has been done with these plants to permit their grouping according to their action on insects.

Apocynaceae

Haplophyton cimicidum A. DC., called the cockroach plant, has been used since time immemorial in Mexico for killing cockroaches, flies, mosquitoes, fleas, lice and other insects. The reports by investigators on the insecticidal value of this plant differ greatly, probably because its chemical composition may vary with growing conditions, such as altitude and soil. Plummer (34) in 1938 reported the dried leaves to be toxic to the Mexican fruitfly. Water extracts of the stems of plants grown in Arizona were

highly toxic as both stomach and contact insecticides when tested against adult house flies. Crude "alkaloid" from this plant proved to be effective against most insects on which it was tested. For example, it was as toxic as pyrethrum to the squash bug and the blister beetle. Other efforts to isolate the toxic constituents were unsuccessful (11, 16).

Asteraceae

Heliopsis longipes (A. Gray) Blake grows in the vicinity of Mexico City where the roots are employed in the preparation of insecticides for local use. A specimen of the roots was sent to the Bureau of Entomology and Plant Quarantine at Beltsville, Maryland, under the name *Erigeron affinis* DC., but when a botanical specimen was received some time later it was identified as *Heliopsis longipes* by S. F. Blake of the Bureau of Plant Industry, Soils, and Agricultural Engineering.

The roots yielded about 1 per cent of an amide (3) which, on the basis of the mistaken identity of the plant, was called "affinin". This amide was later (4) identified as N-isobutyl-2,6,8-decatrienoamide, $C_{14}H_{23}NO$. Affinin has the same paralyzing action and toxicity to house flies as do the pyrethrins, and is also toxic to other insects, including codling moth larvae and several leaf-eating insects.

Bixaceae

The stems and roots of the Mexican plant *Ryania speciosa* Vahl. contain alka-

FIG. 1. Dr. H. L. Haller, chemist of the U. S. Bureau of Entomology and Plant Quarantine, with some thunder god vine, *Tripterygium wilfordii*, grown at Glenn Dale, Md., from cuttings obtained by one of the Department explorers in China where the powdered roots of this species have long been used as an insecticide by market gardeners. (*U.S.D.A. photo by Purdy*).

loids toxic to many kinds of insects and to rats. A proprietary insecticide prepared from this plant was first tested in 1943 against the European corn borer and found to give excellent control, being essentially equal in effectiveness to DDT (33). This material also proved to be toxic to the oriental fruit moth on quince (48). The method of preparing an insecticide from *Ryania* extract and its value for the control of many species of insects are described by Folkers *et al.* (18).

Unpublished results of tests made by the Bureau of Entomology and Plant Quarantine indicate that an extract of this plant is effective against cabbage worms, melonworms, squash bugs, codling moths and black carpet beetle larvae, but ineffective against house flies and both adults and eggs of the body louse. At present the chief use of *Ryania* as an insecticide is for the control of the European corn borer on sweet corn in New York and New Jersey.

Celastraceae

Tripterygium wilfordii Hook. f., lei kung ting or thunder-god vine, is widely cultivated in China where the powdered roots are used extensively for the control of vegetable insects. In 1939 powdered fresh small roots, grown from imported Chinese cuttings by the United States Department of Agriculture at Glenn Dale, Maryland, were found to be very toxic to first-instar larvae of the codling moth, the diamond-back moth and the imported cabbage worm. Alcoholic extracts of the roots were even more toxic. Small roots when powdered were about half as toxic as pyrethrum to the American cockroach, but the medium and large roots were non-toxic (47). Attempts to isolate the active principle, which belongs to the class of ester alkaloids, were unsuccessful, but an insecticidally inert red pigment, tripterine, was obtained from the root bark. This is the same pigment found in the root bark of the related North American bittersweet, *Celastrus scandens* L. (38).

Chenopodiaceae

Anabasis aphylla L., indigenous to the steppes of the Caspian region, contains

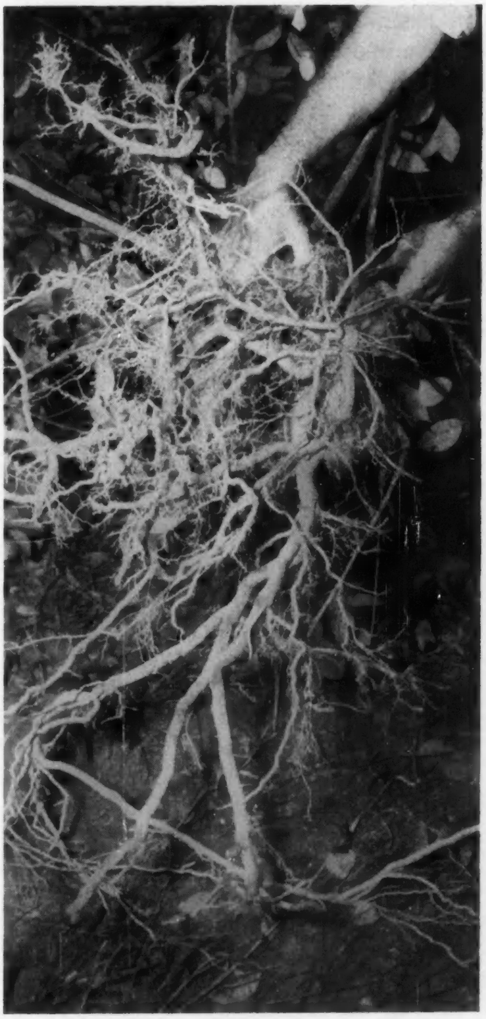

FIG. 2. Roots of the thunder god vine. Chemists and entomologists of the U. S. Department of Agriculture are investigating the possibility of preparing an insecticide from such roots. (*U.S.D.A. photo by Purdy*).

a mixture of alkaloids, chiefly anabasine which is a liquid isomer of nicotine and

closely resembles it in pharmacological and insecticidal properties. About 15 years ago the Russians marketed in this country an insecticide called "anabasine sulfate", 40 per cent solution, which was prepared from *Anabasis* and contained all the alkaloids naturally present in that plant, including about 32 per cent of the anabasine. Tests made by American and Russian entomologists with this commercial insecticide showed it to equal or exceed a 40 per cent nicotine-sulfate solution in toxicity to several kinds of aphids and other soft-bodied insects (35, 37). Laboratory tests with pure anabasine (7) showed it to be more toxic than nicotine to cabbage aphids, nasturtium aphids, pea aphids and citrus red mites, but less toxic than nicotine to celery leaf tiers, large milkweed bugs and spider mites. Anabasine proved to be less toxic than nicotine to codling moth larvae (39). The Russians withdrew anabasine from the American market about 10 years ago, and at present we are without a commercial source of this promising insecticide. Anabasine also is present in certain species of *Nicotiana* (40), especially *N. glauca* R. Grah., the tree tobacco of the Southwest. As much as 6.6 per cent of anabasine was found in the leaves of one of the unpruned hybrids *Nicotiana rustica* L. × *N. glauca* R. Grah. (49), and cultivation of this hybrid appears to be the best way of producing anabasine on a large scale.

Euphorbiaceae

The seeds of *Croton tiglium* L., which contain croton oil as specified in the National Formulary VI, are used in China as an insecticide. Spies (41) in 1933 reported that an acetone extract of the seeds was more toxic than derris extract to goldfish; also that croton resin was more toxic than rotenone. A chemical study of the resin showed that its toxicity is due to the presence of hydroxyl groups. Croton resin is highly vesicant, resembling poison ivy. Although complete methylation of the hydroxyl groups yielded a resin free from vesicant action, the product was also nontoxic (17, 42–44).

Ricinus communis L., the castor-bean plant, has long been reputed to have insecticidal value. In 1940 Holzcker (24) announced a proprietary insecticidal spray material prepared from the leaves, but the value of this has never been established. McIndoo (30) reviewed the literature and concluded that the reports of the efficacy of this plant in killing insects were greatly exaggerated. Haller and McIndoo (23) called attention to the fact that, although ricin, a protein, and ricinine, an alkaloid, are poisonous to vertebrates, little is known of their effect on insects. Both these principles occur in the seeds as well as in other parts of the castor-bean plant. Ricin was found to be non-toxic and ricinine to be highly toxic to codling moth larvae; both proved valueless when tested against house flies. Haller and McIndoo concluded that it is possible that an insecticidal principle is present in the castor-bean plant only under certain conditions with respect to variety, cultural practice and environment. It would appear that the accepted use of the castor-bean plant as a source of insecticide awaits the isolation, identification and methods of analysis of the specific substance or substances toxic to insects.

A valuable synergist for use with pyrethrum, namely N-isobutyl undecyleneamide, is prepared from isobutylamine and undecylenic acid which is obtained on pyrolysis of castor oil. Turkey-red oil, a useful emulsifier for insecticidal oils, is made by the action of sulfuric acid on castor oil.

Fabaceae

In 1928 the Division of Insecticide Investigations began work on a project to find plants that contain insecticidal prin-

ciples. Extracts from a wide range of plant species were tested on goldfish because it had been found that plant extracts non-toxic to fish are also non-toxic to insects, and this test permitted rapid screening out of the large number of materials of little promise. In pursuance of this project the writer, in 1931, collected specimens of *Amorpha fruticosa* L. in North Carolina which were tested by Spies (41). An acetone extract prepared from the whole plant and tested at the rate of 0.2 gram of plant per liter of water killed four goldfish in 278 minutes, as compared with 92 minutes for a similar extract of derris (1.7 per cent rotenone).

Inasmuch as several other plants proved much more toxic to goldfish than *Amorpha fruticosa*, it was not investigated further. In 1937 Moore (32) reported, on the basis of positive Durham tests, that rotenone is present in the roots, stems, bark and seeds of this plant from Nebraska. In 1939 Haller collected a sample of roots in Louisiana which were found to contain no rotenone (25). In 1942 Featherly of the Oklahoma Agricultural and Mechanical College suggested that, inasmuch as this plant is widely distributed throughout the Mississippi River Valley, its seed might serve as a source of rotenone during the war emergency. Seed collected by Featherly and others from widely different locations was examined in the Bureau. Although all the samples gave a positive Durham test and Gross-Smith-Goodhue test, no rotenone or any of the rotenoids could be isolated from any sample. A new glycoside, called "amorphin", $C_{33}H_{40}O_{16}$ (m.p. 151–151.5° C.), was isolated from the seed and was found to react positively to the color tests for rotenone (1, 2).

Brett (9) of the Oklahoma Agricultural Experiment Station has recently reported the results of a study of the insecticidal properties of *Amorpha* which reside largely in resinous pustules on the pods. Tests on 29 species of insects and mites showed that the extract acted as both a stomach and a contact poison, and that it was also repellent to house flies and horn flies for more than 12 hours when sprayed on cattle. Among the insects which are the most susceptible to the insecticidal principle, called "amorpha", are chinch bugs, cotton aphids, pea aphids, chrysanthemum aphids and spotted cucumber beetles. Amorpha had no effect on the skin, but poisoned a guinea pig which was fed an amount equivalent to four grams of pods.

Liliaceae

The seed of the lily *Schoenocaulon officinale* (Schlecht. & Cham.) A. Gray, sabadilla, has been used as an insecticide since the sixteenth century, but until recently this material was employed mainly for the destruction of lice on man and domestic animals (15). The shortage of rotenone caused by the outbreak of war in 1939 stimulated the testing of sabadilla against insects injurious to food crops, and lately it has been sold on a large scale for the control of hemipterous insects, such as squash bugs, chinch bugs, harlequin bugs and *Lygus* bugs (26).

Entomologists at the University of Wisconsin have been leaders in the investigation of the insecticidal possibilities of sabadilla and have patented a method of increasing its toxicity, which consists in heating the powdered seed in kerosene or other solvent to 150° C. for about one hour. If the material is to be used in dusting-powder form the powdered seed is heated without a solvent (5).

During 1945 and 1946 annual imports of sabadilla seed into the United States amounted to 120,000 pounds, mostly from Venezuela.

Pedaliaceae

The seeds of *Sesamum indicum* L. (*S. orientale* L.) yield sesame oil, an edible

semi-drying oil which is of interest to the entomologist because it contains sesamin, a powerful synergist for the active principle of pyrethrum flowers when tested on house flies. The value of sesamin for this purpose has been demonstrated (21, 22). Sesamin alone (0.2 per cent) in refined kerosene killed only 4 per cent of the flies, pyrethrum alone (0.05 per cent) killed 19 per cent, and a mixture of the

FIG. 3. A fruiting plant of sesame, *Sesamum indicum*, on the grounds of the Division of Agriculture for Littoral, west of Guayaquil, Ecuador. Sesame seeds have for generations been the source of an edible oil in the Orient. The oil contains an ingredient, sesamin, that strongly activates the well known insecticide, pyrethrum. (*U.S.D.A. photo by Mitchell*).

two in these concentrations killed 84 per cent. Sesame oil was an ingredient of the pyrethrum liquefied-gas aerosol bombs of which 40,000,000 were used by the armed forces during World War II. The original formula called for 2 per cent of sesame oil; later this was increased to 8 per cent.

Pinaceae

Pine oil obtained from *Pinus palustris* Miller is an ingredient of some sprays utilized for killing and repelling flies on cattle. Pine tar and pine-tar oil have been used in preparations for repelling blow flies from livestock. Of particular interest to the chemist is the recent development of a synthetic insecticide, $C_{10}H_{10}Cl_8$, made by chlorinating camphene, which in turn is made by isomerizing the pinene in turpentine. This chlorinated camphene is a light-yellow waxy product with a very mild piny odor containing 67 to 69 per cent of chlorine (45). Against household insects, such as house fly, German cockroach, black carpet beetle, furniture beetle, webbing clothes moth and bedbug, it displays high toxicity. It rivals DDT in its residual toxicity, but like DDT it has poor knockdown. Bishopp (6) reported that chlorinated camphene (called 3956) is slightly less toxic than DDT as a contact spray against adults of the yellow-fever mosquito, but against the body lice it is more toxic and more persistent than DDT. It has given promising results against insects attacking cotton, and its possibilities as an insecticide against a wide range of agricultural insect pests are being investigated.

Rutaceae

Phellodendron amurense Rupr., the Amur corktree, is a native of eastern Asia, but is cultivated as an ornamental in the United States. The fruit from a tree growing on the grounds of the Capitol, Washington, D. C., was found to be very toxic to mosquito larvae, house flies and codling moth larvae, but non-toxic to southern armyworm larvae (19, 46). The toxic constituent resides in the unsaponifiable portion of the oil, but no crystalline derivative of it could be

obtained. The interesting observation was made that the toxic constituent which, like the pyrethrins, is a fast-acting poison, is very toxic to house flies in acetone solution but not in kerosene.

The petroleum-ether extract of the bark of the southern prickly-ash, *Zanthoxylum clava-herculis* L., contains asarinin which is structurally related to sesamin and, like sesamin, markedly increases the effectiveness of the pyrethrins when tested against house flies. For example, in a series of tests refined kerosene containing 0.05 per cent of pyrethrins killed an average of 25 per cent of the flies after 24 hours, asarinin (0.18 per cent) killed 14 per cent, and a mixture of the two killed 88 per cent (20).

In addition to asarinin the bark of the southern prickly-ash contains a substance highly toxic to house flies which resembles pyrethrum in its action (27).

Simaroubaceae

The water extract of the wood of the trees *Aeschrion excelsa* (Swartz) Kuntze, Jamaica quassia, and *Quassia amara* L., Surinam quassia, finds some use in agriculture as an aphicide (10). It was concluded on the basis of a careful study of the insecticidal properties of quassia (31) that because of its low action an aqueous extract of quassia is much less reliable than nicotine sulfate; moreover, it is not a general insecticide for all aphids. The chemistry of quassia has also been studied (12–14). McGovran *et al.* (28) made laboratory insecticidal tests of a crystalline compound extracted from quassia wood, quassin, on the green peach aphid, the house fly, the Mexican bean beetle and the American cockroach, and found it to have little if any toxicity to these insects.

Quassin and related compounds from quassia are soluble in water and have an intensely bitter taste. These properties suggest their use in tree injection to control insect pests feeding on the sap. Plants whose roots were watered with a dilute solution of quassin were free of aphids, indicating that the quassin was taken up and translocated throughout the plant. Similar results were obtained when soluble selenium compounds were added to cultures of wheat. The advantage of quassin for this purpose is its non-toxicity to man.

Solanaceae

Bowen (8) found the dried leaves of the Australian plant *Duboisia hopwoodii* F. Muell. to contain 3.3 per cent and the larger stems 0.5 per cent of nornicotine. This alkaloid also is found in many species of *Nicotiana*. Smith and Smith (40) examined 29 wild species of the latter genus for alkaloids and reported that five species contained nornicotine only, and 18 contained a mixture of nornicotine and nicotine with the former predominating in most cases. Certain American tobaccos used in the manufacture of low-nicotine cigars have been found to contain as much as 0.7 per cent of nornicotine, and one-eighth of the total alkaloids in certain samples of commercial nicotine sulfate solution was nornicotine.

Nornicotine is more toxic than nicotine to the nasturtium aphid and the pea aphid; about equally toxic to the cabbage aphid, the citrus red mite, and the spider mite; and less toxic to the celery leaf tier, the large milkweed bug (7) and codling moth larvae (39).

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Cork. Since their inception in 1940 under the sponsorship of the late Charles E. McManus, former President and Chairman of the Board of the Crown Cork and Seal Company of Baltimore, Maryland, experimental plantings of cork oak (*Quercus Suber* L.) in the warmer parts of the United States have been expanded to include 22 States. This work has been carried on with the cooperation of Federal and State foresters, county farm agents and other governmental departments. For this purpose more than five tons of cork acorns were gathered in California in the autumn and winter of 1945–1946, and from 1940 to 1945 the distribution of domestically collected acorns increased from 500 pounds to a peak of 13,800 pounds annually. All these acorns, except approximately 200 pounds gathered yearly in Arizona and the South, were obtained in California from trees planted there years ago. In addition, acorns have been imported from Spain, Morocco and Algeria. Acorn germination varies from 50% to 80%.

Since 1940 virgin cork has been stripped from 516 trees of long standing, 20 of them in Arizona and the South, the others in California. These strippings, made from 1940 to 1945, removed 25,658 pounds of cork which has been manufactured into various products and found to be of excellent quality. Second growth cork of high quality has also been removed.

Successful experimental grafts of cork oak on both evergreen and deciduous American oaks have been made, and rooted cuttings have also been used for propagation purposes. Planting of acorns, however, is still the most effective means. (*G. B. Cooke, Scientific Monthly 64: 117. 1947*).

Use of Synthetic Hormones as Weed Killers in Tropical Agriculture

The introduction of chemical weed-control, through the use of highly effective, selective and inexpensive hormone herbicides, permits profitable crop production in the tropics where old tools and methods, combined with an increase in labor costs, have created a serious problem of eradicating the luxuriant growth of tropical weeds.

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Introduction

A FEW years ago my associates and I selected for weed-control experiments a field in which sugar cane had recently been planted. The cane was about one foot above the ground, and an abundance of small weed seedlings gave the field a greenish hue. The weather was warm, as it usually is in Puerto Rico, and the soil was rich and contained ample moisture. When we returned two weeks later, a lush blanket of broad-leaved weeds, some two feet in thickness, had all but covered the cane crop.

At that time the field was sprayed with an 0.075% aqueous solution of the ammonium salt of 2,4-D. Two weeks later, when the plantation was revisited, the weeds were down and the cane was again free to take full advantage of its favorable environment. Half a dollar's worth of 2,4-D per acre had restored the balance in favor of the cane crop.

Phenomenal weed growth is the rule rather than the exception in moist tropical regions. The farmer in these areas is obliged to wage a constant battle against weeds in order to keep them from gaining the upper hand over his crops. Archaic tools, such as the hoe and the machete, are still being widely used as the main implements in weed control. With field labor demanding a higher standard of living it is obvious that its work output has to increase in order to justify the higher pay and still make economical production possible. This cannot be done with the old tools and the old methods. Modern weed killers, in combination with modern applicators and techniques, offer a partial solution to this economic problem. Moreover they reduce the drudgery and back-breaking tasks traditionally associated with agriculture.

Development

Chemical weed control, and even the use of relatively selective herbicides, had its start in Europe at the turn of the century. Copper and iron sulfates were used to kill broad-leaved weeds among cereal crops. Later the practice found a limited use in the United States. More successful was the use of Sinox (sodium dinitroorthocresylate) which was first developed in France and later extensively used in the western United States (35). In the tropics chemical weed control was only sporadically used, probably primarily because of the availability of cheap labor.

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The discovery of 2,4-D has aroused great interest in tropical countries, and the indications are that chemical weed control will become standard practice in tropical agriculture. The reasons for this are at least twofold: first, 2,4-D is by far the best selective herbicide produced so far for tropical use; second, its introduction occurred at a time of social revolutions characterized by the disappearance of cheap coolie labor and increased demands for a higher standard of living by the common field laborer. This necessitates more efficient agricultural practices. Plantation managers were therefore in a receptive mood when the introduction of 2,4-D gave promise of greatly reducing the cost of weeding.

The substance 2,4-D (2,4-dichlorophenoxyacetic acid) is one of a great many synthetic plant-growth regulators. In 1942, at a symposium on hormones at Cold Spring Harbor, N. Y., P. W. Zimmerman of the Boyce Thompson Institute demonstrated some effects of this substance and of many others which he and his associates had synthesized (57). On tomato and other plants the 2,4-D was shown to cause abnormal growth of the youngest leaves. The effect was so striking that the plants appeared to be suffering from "shoe string" virus. Several other substances were shown to have this modifying effect on the growth pattern of leaves, but none was more active than 2,4-D. However, at that time it was not yet realized in this country that these substances could be used for herbicidal purposes. The symposium at Cold Spring Harbor was one of the last before the demands of war suspended the free exchange of information between scientists.

During the war the herbicidal properties of some auxins, especially chlorophenoxy compounds, were realized in England (7, 33, 42) and in the United States (18, 29). In England sodium 4-chloro-2-methyl phenoxyacetate, now known as "methoxone", was developed since late 1941. In the United States the Special Projects Division of the United States Army tested over a thousand compounds for phytocidal activity; no substances which were substantially more toxic than 2,4-D were reported (3, 1). Toxic as the compound is to plants, investigations by the United States Department of Agriculture have shown that it is entirely harmless to man and cattle.

When 2,4-D first became commercially available in limited quantities for experimental purposes, its price, like that of many other synthetic growth regulators, was about one dollar per gram. When the value of 2,4-D to agriculture became apparent, large scale production by the chemical industry made the compound available in quantity and at a very much reduced price. At present it can be bought in ton lots and at a price which is only slightly above 50 cents per pound. To think of growth-regulating substances in terms of tons is indeed strange for hormone physiologists, accustomed to handling these compounds in quantities of micrograms. How rapid the development of 2,4-D for herbicidal purposes was is best told in the words of Kephart of the U.S.D.A. (24): "Thus a substance that was a chemical rarity less than two years ago is now being sold in hundreds of thousands of pounds and creating a whole new industry". In California alone over 50 different brands of 2,4-D herbicides were registered for sale by May 1947.

Action

It is known that the most effective poisons are found among those compounds which resemble, in terms of molecular structure, some hormone, vitamin or other substance necessary for the life of an organism (30, 56). Thus, for ex-

ample, it is believed that the sulfa drugs are such effective bacteriostatic agents because their molecular structure closely resembles that of para-amino-benzoic acid which is an essential growth factor for many microorganisms. Due to structural similarity of the molecule the organism cannot distinguish between the growth inhibitor and the growth factor, and soon the active groups in its protoplasm are saturated with the inhibitor, to the exclusion of the growth factor. This stops the normal function of the protoplasm and thereby prevents growth.

The effectiveness of 2,4-D as a phytocide is probably based on somewhat similar principles. There is ample evidence that in low concentrations 2,4-D acts like hormones of the auxin type. Like these auxins, 2,4-D in concentrations of the order of 5 to 10 parts per million is capable of causing growth curvatures in leaf petioles (57), of preventing preharvest drop of apples (5, 20) and of inducing flower formation in pineapples (46). However, 2,4-D in concentration of 250 parts per million will wipe out by one single spray application 80% of the weed population of the most common sugarcane weeds in Puerto Rico (47, 49).

What is it that makes 2,4-D so effective? In the first place it appears that 2,4-D, due to its close resemblance in molecular make-up to natural auxins, is readily taken up by plants and transported along their normal channels of hormone transport. Experiments at the Bureau of Plant Industry have made it likely that the substance is taken up and transported in the molecular non-dissociated form (55) and that it is transported away from the leaf, to which it is applied, to the growing and other regions of the plant in association with the translocation of sugars and along the same course (32). These observations have important practical implications, viz., alkaline sprays in which the major part of the 2,4-dichlorophenoxyacetic acid occurs in the ionized form are less effective (28), and any action which prevents the leaf from normally translocating its sugars will also tend to prevent the spreading of the herbicide throughout the plant.

In the second place, 2,4-D is an effective phytocide because after its molecules have been transported along the regular channels of hormone transport, they will arrive and apparently accumulate at the site where the natural hormones are most active, *i.e.*, in the protoplasm of the growing meristematic zones. This has been directly demonstrated by the Bureau of Plant Industry in experiments with a growth regulator containing radioactive iodine (55).

The normal function of hormones in the protoplasm is not exactly known, but there is good evidence that plant hormones regulate enzyme processes. In this respect plant hormones resemble animal hormones (2, 21). Among the enzymatic processes which plant hormones affect are some processes of respiration (6, 39, 40, 54). Recently two Chinese workers (23) have given us evidence that the toxic effect of 2,4-D may be due to its interfering with aerobic metabolism. They pointed out that rice, which is capable of anaerobic germination, is little inhibited by 2,4-D, while barley, which will germinate only under aerobic conditions, is strongly inhibited by 2,4-D.

It appears, therefore, that 2,4-D owes its effectiveness to its capacity to penetrate, in a physiological fashion, into the protoplasm of the meristem, thereby upsetting its normal functions, perhaps by interfering with aerobic metabolism. It is well to remember that meristems are among the most vulnerable parts of the plant, but often are so well protected by their location within the plant that they cannot be reached by contact sprays (10). It is only because

the hormone weed killers invade the plant through its normal channels of transport that these well hidden meristems are being reached. An example of this is the cyperaceous weed *Cyperus rotundus* (Fig. 1), known as nut grass in the United States and as "coquí" in Puerto Rico. Its meristem is hidden well below the surface of the soil and, in addition, is enclosed within the base of a

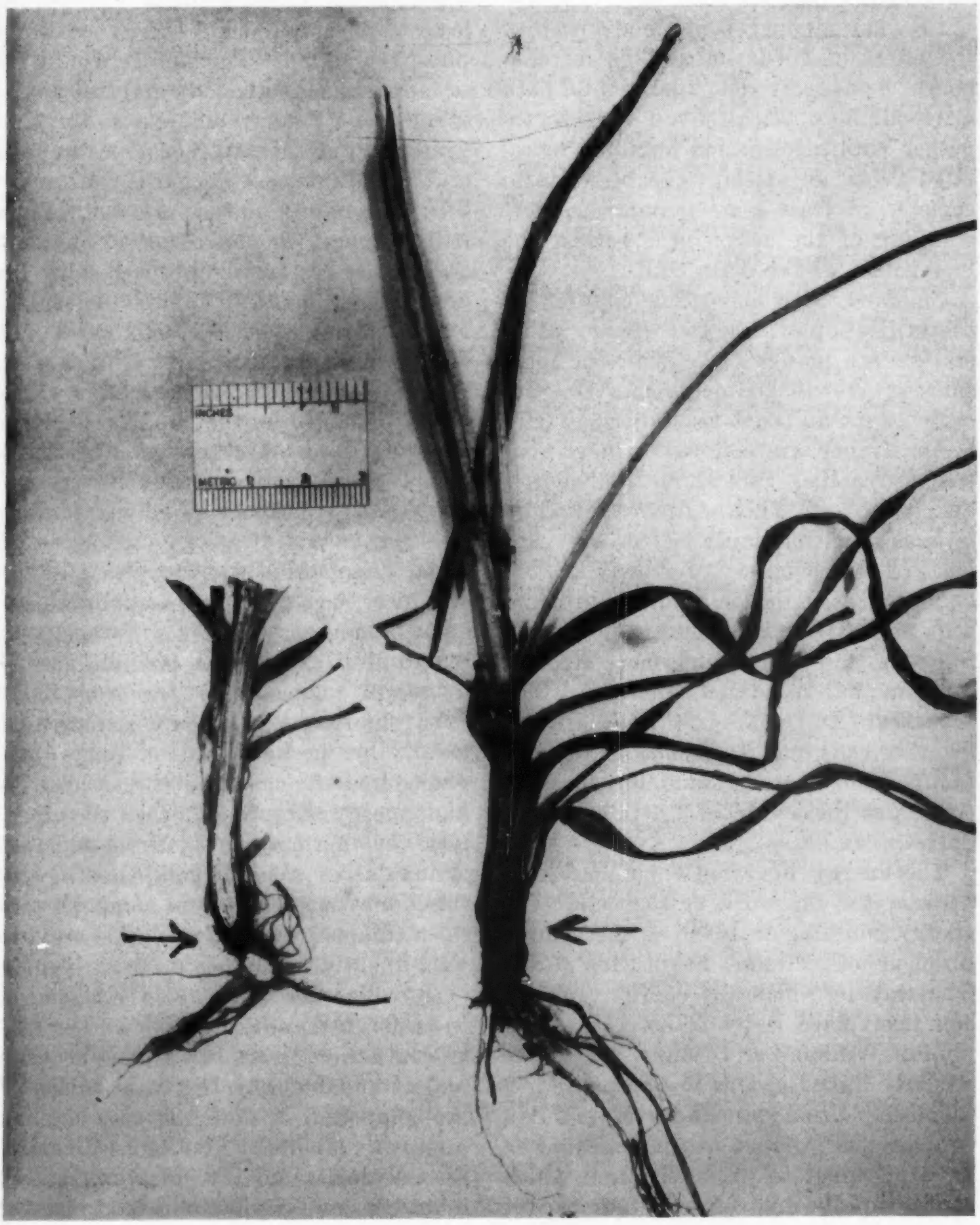

FIG. 1. *Cyperus rotundus,* nutgrass or "coquí", two weeks after being sprayed with 2,4-D. The meristematic region, indicated by an arrow, has disintegrated completely. The plant shown on the left was split lengthwise to show better the region affected by the herbicide.

structure which resembles a stem. No previous effective means of control existed for this weed, which in certain localities in the tropics is a major pest, but with 2,4-D complete eradication has now become possible (48).

In what manner could one visualize the effect of 2,4-D on aerobic metabolism? Some scattered experimental data are available. With the aid of these, together with information obtained in related fields, an attempt can be made to come to at least some tentative understanding of the action of 2,4-D on the metabolism of the plant cell.

Goddard, in a clarifying chapter on the utilization of liberated energy (15), states: "In many of the synthetic reactions of growth an increase in free energy occurs, and such reactions may only occur if they are coupled with an oxidative reaction furnishing the energy deficit". . . . "This widespread oxidative assimilation must be at the very basis of the chemistry of growth. . . ." Oxidative assimilation occurs in growing cells more frequently than in non-growing cells, and seems much more striking in plant than in animal cells (15). The fact that 2,4-D is toxic especially to growing cells and is specifically toxic to plants becomes understandable once one correlates the action of 2,4-D with oxidative assimilation.

The energy liberated in oxidation is utilized for the work of the cell. The energy coupling involved is the central problem of cellular respiration (15). One way in which the energy transfer can take place is by transfer of phosphate. Wildman and Bonner (54) have recently linked auxins to phosphate metabolism. From spinach leaves an auxin protein was isolated which appeared to have phosphatase properties and which could rapidly hydrolyze a number of phosphorylated compounds. Since it has been shown that 2,4-D has many properties of natural auxin it would not be surprising if 2,4-D, after combining with suitable proteins, would likewise be capable of stimulating the liberations of inorganic phosphate from phosphorylated compounds. This may involve direct release of phosphate-bond energy or transphosphorylation. Perhaps it would do so more strongly than the natural auxin indoleacetic acid. One reason for this would be that, as with hormones in general (21), indoleacetic acid is constantly being inactivated in the organism. Thus it has become known recently (41) that an oxidase exists which specifically inactivates the natural auxin indoleacetic acid. Many synthetic auxins would escape such inactivation. It is a fact that 2,4-D ranks among the auxins which persist longest in the plant. Perhaps there are also other reasons why 2,4-D would be a stronger agent in the hydrolysis of phosphorylated compounds than native auxin.

An exaggerated energy release in the organism may have far reaching consequences and may lead to the complete cessation of growth. A possible mechanism was suggested by McElroy (30):

"If inorganic phosphate is increased greatly by the hydrolysis of some phosphorylated intermediate (breakdown of high energy phosphates), then the glycolytic reaction may be so stimulated that the oxidative processes concerned in synthesis may not be able to compete with the available hydrogen acceptors and are consequently inhibited".

Here then we may have a biochemical basis for the understanding of the herbicidal action of 2,4-D. It now becomes understandable why the toxic action of the compound is slow. It also becomes understandable why, due to 2,4-dichlorophenoxyacetic acid, respiration, starch hydrolysis and depletion of food reserves are increased (4, 9, 38), while at the same time the growth process is in-

hibited. A somewhat similar case is known for sea urchin eggs where it has been found that dichloronitrophenol and other substituted phenols will completely inhibit cell division, while at the same time respiration is markedly increased (26).

Selective Action

Another interesting aspect of 2,4-D is its great selectivity. Crafts (10), in an excellent review on selective herbicides, has stated that: "the toxicant will always kill both weed and crop species if brought into intimate contact in sufficient concentration". This is true, no doubt. But it is more obvious with arsenicals or sulfuric acid than with hormone herbicides. The selective action of 2,4-D as a herbicide for sugar cane is such that it would require very special conditions, which rarely exist in practical agriculture, to kill, or even seriously damage, a cane plant with 2,4-D. Whereas the most common cane weeds of moist regions, such as *Commelina* (Fig. 2) and *Ipomea,* were killed with one single aqueous spray of the ammonium salt of 2,4-D at a concentration of 500 parts per million (Fig. 3), not the slightest damage was observed to the cane plant itself. Even concentrations as high as 0.3% which were sprayed on the cane plants themselves were entirely harmless (4, 47). Reports from Louisiana (8) also show that the water soluble salts of 2,4-D cause no damage to sugar cane, and that only when the 2,4-D was applied in high concentrations (0.5%) and in the form of the oil-soluble esters were lesions in the leaves observed.

In addition to sugar cane most other members of the grass family appear to be little sensitive to 2,4-D. Seedlings of grasses, however, although less sensitive than those of many broad-leaved plants, appear to be inhibited by 2,4-D (11, 17, 31, 33). The writer was shown by Crafts at his experimental fields at Davis, California, a series of wild oat plants which had germinated in a soil which was treated with high concentrations of 2,4-D. Not only was the germination much reduced, but the plants that did germinate had tubular leaves with the margins grown together in the same manner as found in coleoptiles and onion leaves. Members of the grass family may also be sensitive to 2,4-D during their reproductive stage. Rice was reported to be sensitive during the heading stage (36).

Among the grasses, all relatively insensitive to 2,4-D, sugar cane appears to be least sensitive. Even during its early stage of development 2,4-D sprays do not appear to affect its growth. In this respect it is well to remember that a young sugar cane field is physiologically not comparable to a field of germinating rice, barley or oats. Sugar cane is commercially propagated by means of cuttings, technically known as "seed pieces". Therefore, the young plants of cane are shoots developing from the lateral buds of the cuttings and not true seedlings. That such shoots might have a metabolism which resembles that of the adult plant rather than that of the seedling stage would not be surprising. For this reason it also becomes understandable why young cane plants are more resistant to 2,4-D than young plants of other members of the grass family which are propagated by seeds. Because in the sugar cane culture the flowers are of no consequence, the plant also escapes a possible injury by 2,4-D during the reproductive stage, as is known for rice (36). The special circumstances just mentioned make sugar cane during its entire growth cycle—under plantation conditions—practically insensitive to 2,4-D, at concentrations necessary to kill weeds.

This relative insensitivity is probably not due to the failure of 2,4-D to pene-

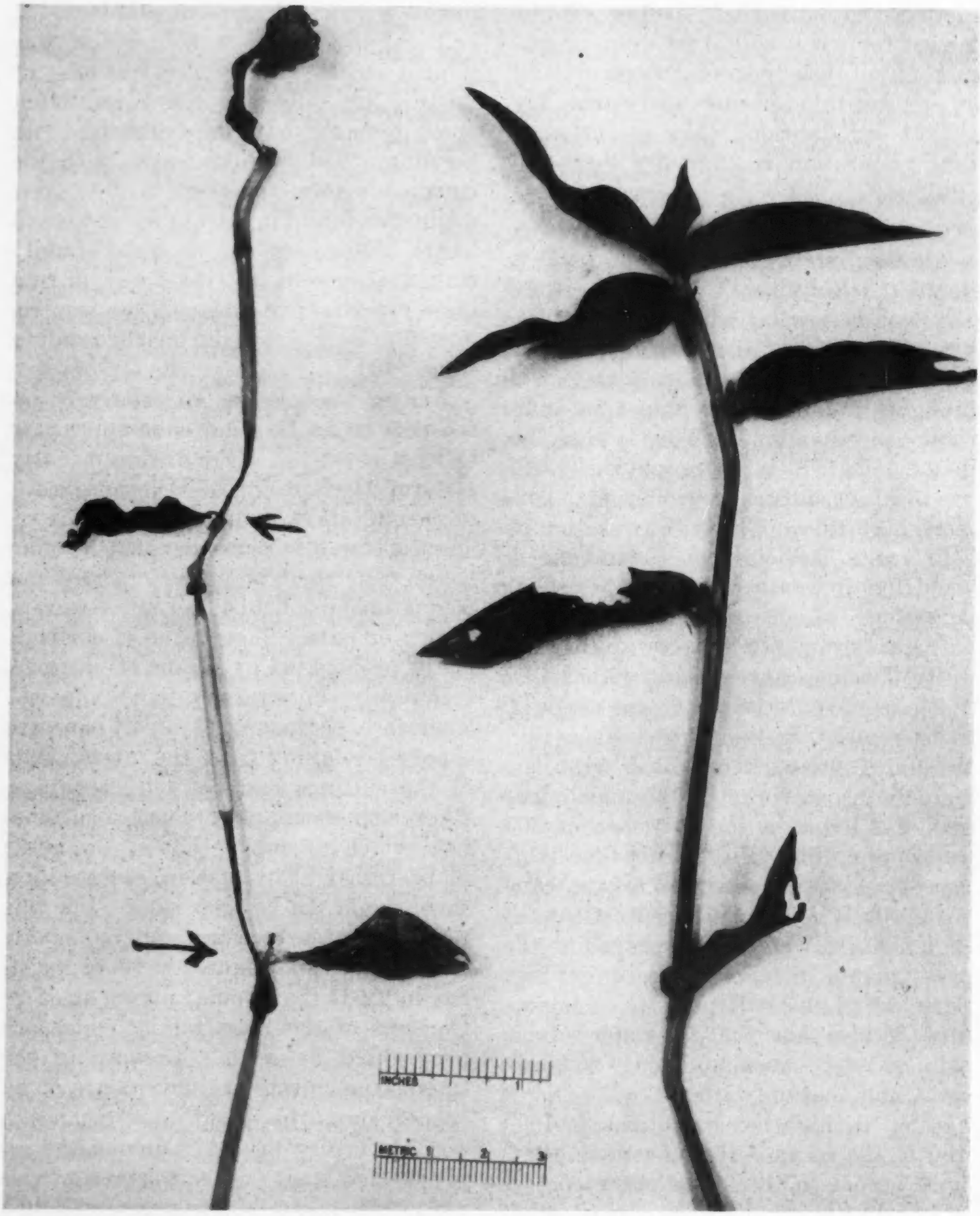

FIG. 2. *Commelina longicaulis*, wandering jew or "cohitre", two weeks after being sprayed with 2,4-D. The intercalary growth regions, indicated by arrows, have disintegrated completely. Right: untreated control.

trate the sugar cane plant. It is known that auxins, such as naphthaleneacetic acid, penetrate sugar cane stems (45). It is also known that other hormone-like regulators penetrate into barley plants, without, however, causing a significant reduction in their growth. The latter was shown by means of radioactive iodine which was used as a tracer in 2-iodo-3-nitrobenzoic acid (55). The

problem of why certain plants, at certain stages of development, are sensitive to 2,4-D, while other plants species are not, will probably be solved soon after we understand in detail where and how the natural auxins enter into the metabolic processes of the plant.

Members of the grass family are not the only plants which are relatively insensitive to 2,4-D. Several broad-leaved plants are also relatively insensitive to the compound. Even within the same taxonomic group some plants may be sensitive, while others are not. Thus within the legumes it was often found that plants of a herbaceous character are highly sensitive, while many of their woody representatives are not. Among the sensitive herbaceous legumes are the bean and *Stizolobium pruritum,* also known as "pica pica", which is feared by sugar cane workers for the stinging hairs on its pods (47). Among the legumes which resist 2,4-D are *Erythrina* species, which serve as coffee shade trees, and *Derris elliptica* (53), a woody creeper the roots of which yield the insecticide rotenone.

Coffee is another plant of great economical importance which seems to be immune to aqueous 2,4-D sprays. In coffee seedlings as well as mature trees, no damaging effects of 2,4-D were found (47). This is of considerable economic importance, as coffee plantations are habitually plagued by a number of harmful weeds which are difficult to eradicate by the primitive traditional methods: *Clerodendrum* threatens to overshadow young plantings; a variety of vines, among which *Ipomea* species are prominent, is an ever present menace to the crowns of mature coffee plants; and impenetrable bushes of the giant nettle, *Urera,* make the tasks of workers in coffee plantations difficult. All these coffee weeds are highly susceptible to 2,4-D sprays in low concentrations.

There is a striking difference in sensitivity to 2,4-D in various stages in the growth cycle of plants. We have already mentioned the grasses which are more sensitive in the seedling stage than later in life. It appears that broad-leaved plants, too, are more sensitive in their early stages of development than in later ones. Weeds in the seedling stage are known to be most susceptible to eradication by 2,4-D. The following may illustrate this:

Shortly after 2,4-D had begun to become available to commercial growers, the operator of a large sugar cane plantation asked for a sample of 2,4-D. This was promptly sent to him. The plantation in question was located in a moist region, where in our experience weed species occur which are highly susceptible to 2,4-D. For this reason we expected excellent results, and were much surprised when the grower reported that the new weed killer was no good since it had not killed the weeds as expected. Upon investigation we found that the planter, anxious to give the new herbicide a tough test, had applied the 2,4-D solution to a dense stand of tall, *mature* weeds. Such weeds are not much harmed by hormone herbicides. We left the plantation after having suggested that a new trial be started on a dense stand of *young,* actively growing weeds. The next report which we had from the grower was that he had ordered three tons of 2,4-D!

Mortality Curves

The sensitivity of a weed to 2,4-D sprays can be expressed graphically by plotting the percentage mortality against the concentration of the herbicide. The differences in sensitivity between plant species are reflected in mortality curves of different shapes, ranging from steep curves for the highly sensitive weeds to flat curves for the highly resistant spe-

cies. For practical purposes, however, the weeds of Puerto Rico have been divided into four sensitivity groups, each having a specific mortality-concentration curve (47, 49, and Fig. 3). Group I comprises plants which are highly sensitive to 2,4-D and which can be eradicated by concentrations of 0.05%. Group II includes plants which can be eradicated by concentrations of 0.15% 2,4-D. Group III contains plants which can be eradicated by concentrations between 0.2 and 0.3%; while, finally, group IV includes plants which are relatively insensitive to 2,4-D. The majority of the most noxious sugar cane and coffee weeds belong to group I, and can be eradicated at a cost of less than 30 cents worth of chemical per acre (47).

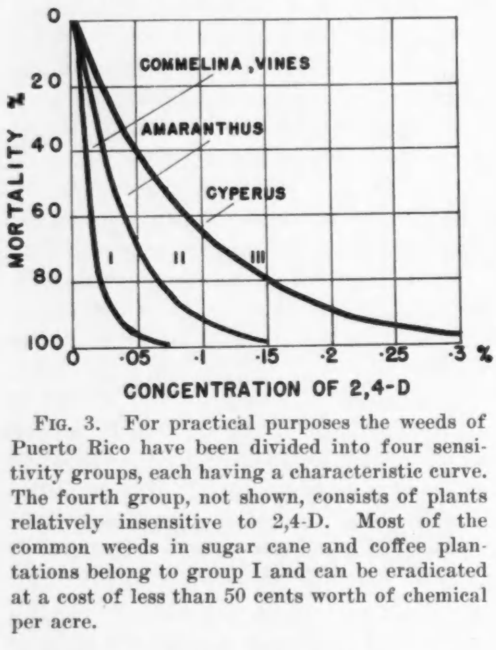

FIG. 3. For practical purposes the weeds of Puerto Rico have been divided into four sensitivity groups, each having a characteristic curve. The fourth group, not shown, consists of plants relatively insensitive to 2,4-D. Most of the common weeds in sugar cane and coffee plantations belong to group I and can be eradicated at a cost of less than 50 cents worth of chemical per acre.

Succession

When growing conditions continue to be favorable for weeds, those killed by 2,4-D will be replaced by others which escape the lethal effect of the compound. It is a fact that the growth of grass weeds is indirectly promoted by 2,4-D sprays. This becomes understandable if one considers the following: A field of crop plants, together with its weeds, represents a plant population. The individual plant species which make up the population are in constant balance with each other. When one species is suppressed or killed the remaining members of the population compete with each other to take its place. This is illustrated by the happenings in the cane field which was mentioned at the beginning of this article. Before 2,4-D treatment this field was dominated by broadleaved weeds, especially *Cleome*. A close inspection of the weed population revealed also the presence of numerous small weed grasses (*Digitaria*). These grasses, however, being sun lovers, could not develop because the fast growing *Cleome* plants overshadowed them. No sooner was the *Cleome* killed by the 2,4-D sprays than these grasses sprang into prominence. In the meantime, however, the sugar cane plants themselves had grown and were overshadowing and thereby checking the development of the weed grasses.

It would seem, therefore, that 2,4-D cannot be used as the exclusive method in a weed control program, and it will probably prove most efficaceous if mechanical weedings or applications of relatively non-selective herbicides be alternated with 2,4-D treatments (44, 48).

Possible Further Improvements

It is always hazardous to predict future developments, especially in a field as new as that of the hormone herbicides. The spectacular development of 2,4-D which we have witnessed in recent years could hardly have been predicted. Nevertheless, on the basis of present knowledge it seems possible to indicate

along which lines further development might take place.

Improvements in equipment are likely, as at present the characteristics of 2,4-D are not fully taken advantage of. One of these characteristics is that hormone herbicides are active in small quantities. Yet, because of their relatively low solubility in water, up to recently applications of from 100 to 300 gallons per acre have been necessary when aqueous sprays were used. Such sprays are popular in Puerto Rico at present because they allow purchase of the chemical in its cheapest form, the crystals of the 2,4-D acid. In addition, the solutions are easily made with the aid of small quantities of ammonia, and common applicators, ranging from knapsack sprayers to mechanical equipment designed for insecticides, can be used. Nevertheless, the hauling of the large quantities of water necessary for these sprays is hardly efficient. It should be possible to use the hormone herbicides in a much more concentrated form, perhaps using carriers other than water. Under such conditions it should be possible to reduce the amount of herbicidal material to a few gallons per acre. The equipment necessary for such operations is not generally available yet, but there is evidence that thought is being given to this problem. Thus Hamner and Tukey described recently an atomizing nozzle which makes it possible to apply concentrated oils, oil emulsions or water solutions of 2,4-D at as low a rate as three gallons per acre (16). Nozzles of this general type already have found wide application in California where low-volume spraying is becoming a standard practice. Tributyl phosphate has been found a suitable cosolvent of 2,4-D for use in mineral oils (14); at ordinary temperature this compound dissolves 36% by weight of 2,4-D. The triethanolamine salt of 2,4-D is so soluble that 0.7 lb. can be applied in less than two gallons of water (22), and some commercial preparations hold as much as 3.5 lbs. per gallon of concentrate.

Application of hormone herbicides in dusts is a possibility, and so are applications by means of fog generators (50) of the type used for developing smoke screens during the war. However, except when the plantations to be treated are quite isolated, there is real danger that clouds of herbicidal material may drift beyond their objective and cause serious damage to sensitive vegetation. Law suits may result which could easily offset the gains obtained by the more efficient method of weed control. In addition, the size of the particles produced by fog generators is naturally very small, and these will have such a high surface tension that they will tend to remain adrift rather than stick to plant material as intended.

Another field in which it seems much progress can be made is that of developing special herbicides for specific crops. Light oils, such as Stoddard solvent or stove oil (10, 27), are being used with success specifically for crops belonging to the Umbelliferae, such as carrots and celery. It has been reported from England (7) that 4-chloro-2-methyl phenoxyacetate is less likely to injure cereal crops than 2,4-D. Isopropylphenyl carbamate has become known, which when added to the soil is more toxic to grasses than to broad-leaved weeds (12), thus having a selective effect which is the reverse of that of 2,4-D, Sinox and several of the older selective herbicides. In addition, 2,4,5-trichlorophenoxyacetic acid has been reported highly toxic to potatoes, much more so than 2,4-D. These examples show that it is possible to match chemicals with vegetation, for either diminished or increased toxicity.

The use of activators and sensitizers is another field in which progress could be made. Two papers have already ap-

peared which indicate that the use of additives to 2,4-D may increase its effectiveness. Phenylacetic acid (25) and onion extract (28) were shown to have such effect. The writer was also shown at the Federal Experiment Station at Mayaguez the eradication of *Cynodon dactylon,* a weed grass, by a combination of 2,4-D and a low concentration of an arsenical (51). The grass is unaffected by 2,4-D alone and is damaged, but not eradicated, by the arsenical alone. A mixture of the two compounds seemed to eradicate the weed grass completely. This is a rather surprising observation in view of the fact that previous experiments have shown that 2,4-D will not spread inside a plant unless normal photosynthesis and translocation can take place (32). Arsenicals would be expected to cause such interference and therefore would tend to render 2,4-D less effective. In the example of *Cynodon,* cited above, the reverse was observed. Hence the arsenicals made 2,4-D toxic to the grass, or perhaps 2,4-D enhanced the toxicity of the arsenicals. From Louisiana it has been reported (8) that flame cultivation makes sugar cane plants more susceptible to injury by 2,4-D esters. The nodes are affected.

Last but not least, the way in which the hormone herbicides are used is subject to many modifications and improvements. One of the most promising techniques is that of pre-emergence weeding. By means of this method weed seedlings are killed before the emergence of the crop, so that the crop will not require the usual time-consuming and expensive hoeing and cultivation. Hormone herbicides, which persist under humid conditions in the soil for only a few weeks, are well suited to remove weed seedlings from the fields prior to planting. Because the action of these herbicides disappears from the soil before the crops are started, the use of 2,4-D is not restricted to non-sensitive crops, but may be used as well for crops sensitive to 2,4-D, such as leafy vegetables and beans. Under drier conditions, as occur in California, 2,4-D persists for longer periods in the soil, and diesel fuel oils may be used as pre-emergence sprays. Kephart (24), speaking about pre-emergence weeding, has estimated that: "This might well reduce the cost of producing field crops one-fourth".

Tropical use of 2,4-D and other hormonal herbicides is not restricted to the usual plantation and cash crops, but can be used for improvement of pastures as well. The author and his associates had an opportunity to help with brush eradication of pastures on a nearby island. Many thorny and undesirable shrubs which tend to hamper grass production (37) will regenerate from the stump after they have been cut down. Application of strong 2,4-D solutions on the cut surface prevented such regeneration and gave the pasture improvement a more permanent character. Similar results were reported in the continental United States (19).

When Not to Weed

In an article on weed control in the tropics mention should be made of the fact that under certain conditions weeds may be highly beneficial. This is especially so when they form a protective cover over the soil. In tropical regions rains are often torrential and the individual drops large. The impact of these drops on unprotected soils will invariably loosen soil particles. Once this has happened these particles are carried away by the run-off water, and large amounts of top soil are lost in an amazingly short time (12). In tropical regions with the sun overhead many hours of the day, overheating of the upper layers of the unprotected soil is common. Temperatures of over 110° F. can be found on an average day one inch below the surface of unprotected soils

(44), and even six inches below the surface, temperatures of 94° were recorded, which is 15° higher than maximal temperatures in soil protected by a mulch (52). It will be clear, therefore, that the dangers of excessive and unjudicious weeding are perhaps even greater in the tropics than in the middle latitudes. Before attempting weed control the farm manager has to ask: "Is weeding necessary, and if so, to what extent".

The rapidly growing weeds, discussed at the beginning of this article, which threaten the very existence of the sugar-cane crop is a clear-cut case in favor of drastic weed eradication. Similarly, the removal of *Commelina* and vines from sugar cane plantations, in order to have a clean surface at harvest time, is an obvious operation. A thick cover of weeds does not allow cane cutters to cut the stalks close to the ground, which would result in the loss of the valuable basal part of the stalk. In addition, the ratoon crop which follows a crop that is cut too high is subject to damage by wind which causes "falling" (43). The need for eradicating a number of noxious vines is equally clear: In sugar-cane fields the presence of *Stizolobium* ("pica pica") makes it impossible for men to move through the plantations without danger of injury by its stinging hairs; in the tree nursery the excessive shading caused by *Ipomea* and *Cissus* vines prevents the proper development of the young trees, while the tree-strangling habit of some of these vines tends to deform the trunks of the nursery stock; in coffee plantations these same vines tend to overshadow the crowns of the coffee plants thereby materially reducing their yield and often endangering the very existence of the plantation.

Less clear-cut cases for the need of weeding are found in the ground cover of coffee plantations. Here the giant nettle (*Urera baccifera*) and the dumb cane (*Dieffenbachia seguine*), both of which are injurious to plantation workers, have to be removed. On the other hand it is highly beneficial to leave a ground cover as a protection against soil erosion. *Commelina,* which is undesirable in sugar plantations, forms a beneficial ground cover in coffee plantations, and so do a large variety of other small weeds.

Excessive weeding, in the opinion of the author, is found in some Puerto Rican pineapple plantations. In these plantations clean cultivation is practiced. In order to accomplish this, a cultivator is pulled by an ox between the rows of pineapple plants at rather frequent intervals. The animal, however, refuses to move between these rows if the sharp leaves of the pineapple obstruct its path. Accordingly, men with machetes are sent into the fields to cut wide paths between the rows. In considering this situation one finds that much is lost and little gained. The cutting of the pineapple leaves reduces their photosynthetic area, which, in turn, results in a decreased fruit weight (46). It is also known that pineapple plants, being bromeliads—a family of epiphytes—have a poor and shallow root system. Moving the cultivator between the rows invariably causes root damage. In addition, removal of all weeds plus the cutting of the leaves causes the soil to be unnecessarily exposed to the sun. Knowing the characteristics of the root system of the pineapple it does not seem hazardous to venture the guess that soil protection would improve the growth of its root system.

All these disadvantages of clean cultivation in the pineapple field do not seem to bring with them any tangible advantage. The author became convinced of this when a plantation in the drier regions of Puerto Rico, in which periodic observations were made, was not weeded for a considerable time. The plantation was difficult to traverse on account of

the weed growth, and to an apostle of clean cultvation it must have presented a terrible sight. Nevertheless, its pineapple plants grew beautifully and produced an excellent crop.

Clean cultivation was abandoned in Java when the planters realized that the relatively slightly harmful effect of "benign weeds" is offset by their beneficial effect to the soil and to crop plants (34). Of course, no general rule can be made. The intelligent plantation manager, aided by specialists in weed control, will have to decide in practically every individual case whether weeding is really necessary, and if so, to what extent and with what methods.

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Utilization Abstracts

Wooden Boats of Ecuador. In the early wooden-ship building industry of Ecuador, beginning after the Spanish conquest in 1535, "hemp for cordage was grown in Chile, cotton for canvas in Peru, and tallow was obtained from cattle raised locally or imported from Chile. Underwater caulking was made of fiber from coconut husks; above the water line hemp was used. Pulleys and deadeyes were made of local wood". Today, despite the inroads of steel construction, there is still a great amount of wood ship construction for coastwise and river traffic. The woods principally used in this work are known as mangle, guayacan, black laurel, and amarillo. [The precise species can not be given—Ed.].

Mangle is one of the mangroves, which, unlike most of them, "grows very straight and to a great size in the coastal salt water swamps". The wood is very heavy, strong and moderately durable. According to local opinion it gives best service if stored under water for six months after felling. One fell-length piece, hand squared on all sides with an ax and adze, is used as the keel in boats, and must be replaced in three to eight years. Mangle is used also for stringers, clamps and shelves. "Other squared logs or timbers of amarillo and black laurel are brought in from more distant forests, whip-sawn into planking and decking, and stacked for air seasoning". And "men are sent into the nearby hills to obtain natural crooks of such 'incorruptible' species as guayacan, guachapeli, and madera negra, for stem, sternposts, frames, deck beams and knees. These parts are selected in the standing tree for their particular use in the finished boat, crooks being selected that are best suited to each member. After felling, the parts are worked and shaped to rough dimensions to reduce weight before being taken from the forest".

"The planks below the water line are of amarillo, a species highly regarded by Ecuadorian builders for its strength, durability, and resistance to attack by marine borers. Above water line black laurel is used, a species that gives good service but is not so highly regarded as amarillo. The same species are used for decking".

"Planking seams below water line are caulked with coconut fiber, a material said to be more durable under water than hemp caulking and, of course, much less expensive". "Above water line and on deck, hemp caulking is used, since it withstands alternate wetting and drying better than does the coconut fiber".

Black laurel is also used for planking and decking. (*L. V. Teesdale, American Forests 52: 410. 1946*).

Flax, Coir, Ramie, Henequen. Canada's 15,700 acres of flax will produce an estimated 930 short tons of graded scutched flax and 1,800 short tons of tow in the 1946–1947 season. "A new variety of flax has been produced by the U. S. Dept. of Agriculture under the name of 'Cascade'. It is claimed to be resistant to wilt, immune from rust, of tall growth, and to have an important bearing upon the future of flax production in the U.S.A.".

The 47 centers of coir coconut husk fiber yarn centers in Ceylon are enjoying a boom to meet increased demands for the material by gunny bag manufacturers in South Africa.

"The Florida Ramie Products Corporation has set up a plant for the decortication of ramie [*Boehmeria nivea*] at Belle Glade, Florida, with an estimated investment of 300,000 dollars.

"The plant reaches an hourly output of 500 pounds of peeled fibre after two months of operation. Its total production is being taken by the Navy for packing warship propeller shafts".

"Production of henequen [*Agave fourcroydes*] fibre in Cuba during 1946 is estimated at 15,000 metric tons, and the 1947 production is expected to be slightly larger. The greater part of the production is consumed locally. During the third quarter of 1946, 370 metric tons of henequen rope and twine were exported [from Cuba], principal destinations being the United States and Argentina". (*Anon., Fibres 8(3): 101. 1947*).